الملتقى العالمى للطاقة « 88 »

energex

' المعرفة حق طبيعى لكل انسان '

مجلدات بحوث الملتقى العالمى للطاقة 88

PROCEEDINGS OF ENERGEX 88
THE GLOBAL ENERGY FORUM

NOVEMBER 25 – 30,1988.

المجلد الأول
النفط والغاز
الفصول من I الى VI

VOLUME 1
OIL & GAS
SECTIONS: I – VI

TRIPOLI , LIBYA
(G.S.P.L.A.J.)

FOREWORD

The ENERGEX'88 an International Energy Conference is the second in its series of assembly for discussing and documenting the trends of research and development in the areas of oil and gas, solar energy, wind energy, nuclear energy, hydrogen, biomass and other forms of energy. The first conference of this global forum was held in Regina, Canada in 1984. The choice of Tripoli as the venue of this conference is important from the view points of its recent development in oil and gas together with its researches in renewable energy sources; in addition to the wishes of the International and Arab Scientific Community. The organization of this conference is the scientific achievement of Research Units of Jamahiriya and its success was with the users for applying world peace.

At the present terrain of technological development the energy demand and its utilisation are increasing every day both in developed and in developing countries. Many research groups are trying to design appropriate systems and devices for optimizing energy economy through research and development. For this purpose most of the countries spend a substantial amount of budget every year for planning, developing, conserving and managing the available sources of energy, and people are becoming more conscious about energy. As a result a rapid propagation of information and transfer of technology are taking place throughout the world. The ENERGEX'88 creates an environment for meeting energy experts and researchers for exchanging knowledge and disseminating technical know-how of complex technologies, and the related energy topics.

These volumes of Proceedings present contributory papers and plenary lectures grouped subject wise under ninteen categories for convenience to the readers. It contains one hundred and ninteen papers from as many as fifty countries representing a wide band spectrum of research and development work being carried out by investigators from Africa, Asia, Europe, North and South America. The papers presented here, give information of all major energy aspects useful to researchers and end users.

With deep sincerity I acknowledge the assistance and cooperation of the members of Steering Committee and International Committee. I appreciate the plenary lecturers for contributing the papers and attending the conference. Special thanks are also due to the authors who have shown interest to the conference and published their research papers in this Proceedings, and those who reviewed the papers.

Here, I take this opportunity to thank the sponsors and all personnel who have put their best efforts in publishing these volumes.

Dr. M. A. MUNTASSER
CHAIRMAN, ENERGEX'88

ORGANISING COMMITTEE

1. Dr. M. A. Muntasser
2. Dr. S. M. Abugres
3. Dr. A. A. Ballut
4. Dr. F. M. Bara
5. Dr. M. M. Sassi
6. Mr. S. Ghezzewi

SCIENTIFIC COMMITTEE

1. Dr. S. M. Abugres
2. Dr. M. A. Muntasser
3. Dr. A. A. Ballut
4. Dr. F. M. Bara
5. Dr. T.R. Dali

INTERNATIONAL STEERING COMMITTEE

1. Dr. M. A. Muntasser
2. Dr. A. Ben-Omran
3. Dr. P. J. Catania
4. Dr. A. Sayigh
5. Dr. Michel Grenon
6. Dr. J. Nanda
7. Dr. Ken Ichi Kimura

عيسى يوسف اللويشي

NATIONAL STEERING COMMITTEE

1. Dr. A. A. Ballut
2. Engr. A. Fares
3. Dr. M. El-Ousta
4. Dr. A. El-Shebani
5. Dr. M. El-Dweeb
6. Dr. A. El-Sheikh
7. Engr. A. Elmislati
8. Dr. A. Hussain

REGISTRATION COMMITTEE

1. Dr. M. M. Sassi
2. Dr. Fakhry I.
3. Dr.S.M. N. Islam
4. Mr. Sami Mousa

PUBLICATION AND ADVERTISEMENT COMMITTEE

1. Dr. B. Aburween
2. Mr. D. Teebar
3. Mr. K.H. Hassan
4. Mr. M. Elereefy

EXPOSITION COMMITTEE

1. Dr. M. Mashena
2. Dr. F. Al-Akkari
3. Dr. F. Matuge
4. Dr. T. Gaballa

RECEPTION, ACCOMODATION & TRANSPORT COMMITTEE

1. Engr. A. Bozidi
2. Engr. A. Cadamasee
3. Engr. A. Ashoor
4. Engr. A. Dikna
5. Engr. A. Aswad
6. Mr. A. Obia
7. Member Immigration
8. Member Custom
9. Member Airlines

FINANCIAL COMMITTEE

1. Mr. S. Shaafy
2. Mr. R. Sunni
3. Mr. Bashir Daw
4. Mr. B. Daou

CONTENTS

SECTION I. PLENARY LECTURES

SECTION III. EXPLORATION, DISTRIBUTION AND MANAGEMENT

SECTION IV. ECONOMY AND CONSERVATION

AUTHORS INDEX

https://archive.org/details/@hassan_ibrahem

SECTION I

PLENARY LECTURES

https://archive.org/details/@hassan_ibrahem

VALIDATION OF BUILDING ENERGY ANALYSIS COMPUTER PROGRAMS

G. K. Yuill, Ph.D.
G. K. Yuill and Associates Ltd.
Winnipeg, Canada

ABSTRACT

Many building energy analysis (BEA) computer programs have been developed in the past few years. All the programs that are useful for analyzing the annual energy consumption of a building in practical situations are based on substantial simplifications of the fundamental equations of thermodynamics and heat transfer.

An external validation of a BEA program tests these simplifications, the algorithms which have been developed to implement them, and the program in which these algorithms are used.

The present paper describes the difficulties of attempting to validate such a program. Some previous attempts at validation are described. Finally, the results of several more recent validation exercises which have been more successful are presented.

1. INTRODUCTION

Building energy analysis (BEA) computer programs calculate the energy consumption of a building for a particular period (usually a year) as a function of the physical description of the building, the schedules of its usage and occupancy, and the local weather data for the year in question. Most of the more accurate computer programs carry out one heat balance calculation per hour and account for transient heat transfer in the massive components of the building. There are many programs which take simpler approaches, including the neglect of transient effects, down to the simplest programs which may do only one heat balance per month based on an average ambient temperature.

The developers of a computer program may validate it before it is publicly released, but there is also a need for an external validation to assure users of the accuracy of a particular program. In some jurisdictions, building energy analysis may be required to prove conformance of building designs with legislated energy budgets. The building code authorities will require assurance that the programs used are accurate enough to be applied for this purpose.

In many cases the computer program listing will not be available for inspection by those who are verifying it, because it will be kept secret for commercial reasons. Even when this is not the case, it is not practicable to verify a program as complex as most BEA programs by review of the program listing. It is usually necessary to treat the program as a black box and to verify it by comparison of its output with other data that is regarded as valid.

This paper is a review of several of the verification methods which have been used, by ourselves and by others. The failures of some approaches, and the successes of some others are described and explained.

2. VALIDATION PROCEDURES

There are three general methods of obtaining validated data for use in the verification of BEA computer programs. These are:

i. the use of data obtained by experiment,
ii. the use of results obtained by theoretical analysis, based on the fundamental laws of physics or on well validated empirical correlations, and

iii. the use of data obtained by the application of other energy analysis computer programs.

Many successful evaluations of BEA programs against experimental data have been carried out. Some [1,2,3] have compared the monthly and annual predictions of the program to be validated against the monitored energy use data for buildings. Others [4,5,6] have used smaller numbers of buildings, but have used much more detailed monitoring. This allows comparison of energy usage or local temperature on an hour-by-hour basis.

A third experimental approach is the use of test cells instead of real buildings. These may be outdoor test huts exposed to real weather [7], or they may be laboratory test cells [8,9].

Theoretical analysis provides a firm basis for the validation of specific elements of energy analysis computer programs. It can only be applied to certain cases which have analytical solutions, but for these cases, the reliability of the verification is very high. One example is transient conduction [10,11]. Another is the performance of heating, ventilating, and air conditioning equipment. [12] This equipment is usually simulated using a steady state model which takes into account only the present hour's operating conditions. This makes analytical verification particularly easy.

The last of the three main approaches to validation uses one program as the basis of comparison of another. This requires, of course, that the BEA program being used as the basis for comparison be well validated itself. One way of doing this is to use a BEA program which has been well validated [13]. A second approach is to run several well known and well respected energy analysis computer programs, and to consider the results to be reliable if they all agree reasonably well. [14] These two approaches are most applicable when the program to be validated is believed to be simpler or less accurate than the program or programs used as a basis for comparison.

A third validation method which uses another computer program for comparison is based on the use of a program which is much more detailed and accurate than would be possible in a BEA program. For example, a mainframe finite element program could be used to calculate the transient heat transfer in the ground to validate a simple below grade heat loss model which forms part of a BEA program. [15]

In the following section, some of the practical advantages and disadvantages of each of these validation methods for BEA programs are reviewed.

3. ASSESSMENT OF VALIDATION PROCEDURES

Engineers are pragmatic people. They want their computer programs to be validated against the "real world." However, validating a large, complex computer program against results obtained in a large, complex building is a difficult and expensive task, with many uncertainties. The major uncertainty in the first empirical validation method, comparison of predicted and actual fuel bills, is the meaning of the results. Is the agreement good because the program is good, or because the errors cancelled out? If the agreement is bad, is it because the program is bad, because the experimental data is bad, or because the program user made a mistake? If the program is bad, what is the problem; a fundamental weakness in a model, or a bug that could be easily eliminated?

These problems are very real. We have heard of several validation efforts that failed because the program users did not use them correctly. We have been involved in a validation project which was unsuccessful on the first attempt because the supposed properties of the glazing material and the wall insulation were incorrect. This data was later determined empirically, but this was very expensive.

Empirical validation can be made more accurate by comparing more detailed results than monthly or annual fuel bills. Hour-by-hour comparisons of predicted or measured energy consumptions or space temperatures are a much more rigorous test of a program. If they agree well, it is unlikely that this is the result of errors cancelling one another. On the other hand, this kind of comparison requires more effort and more monitoring equipment.

In summary, empirical verification of BEA programs against real buildings is limited by the need to ensure that all the input data and measured data is very accurately known. This costs a great deal of money, which limits the validation to a small number of cases. This in turn means that the exercise only validates a limited number of program paths.

Test cell data can be determined with much greater precision than real building data. However, test cells are expensive to build, since they have no other purpose. Another disadvantage of test cells is that they can be used to validate only a limited set of program elements, and for a limited set of imposed conditions.

Analytical solutions are usually cheaper to obtain than test cell data, but like test cell data they are very limited in the range of program elements they can test, and the range of conditions they can be applied to. Thus analytical verification can

never completely validate a computer program. On the other hand, the low cost and high accuracy of analytical solutions make them a logical first step in most BEA program validation projects.

The use of a more complex program, such as a finite element program for transient heat transfer, to validate a BEA program shares the advantages and disadvantages of the analytical solution. This method can cover a slightly wider range of cases than analysis, but it costs more as well.

The method of validation which has the widest application is comparison with one or more other energy analysis computer programs. This approach is reasonably economical, but its greatest advantage is that there is no limit to the range of cases that can be validated, including cases that do not have analytical solutions, and cases that can not occur in nature. The value of the latter capability may not be obvious at first, but will be explained further in the next section of this paper.

4. APPROACHES TO VALIDATION BY PROGRAM COMPARISON

There are two general approaches to validation by comparison with already validated computer programs. One is to compare results using a year of realistic weather for a realistic building. The other is to set up artificial test cases which exercise particular features of the program to be verified. Each approach has its own advantages.

The advantage of using artificial test cases is that this method is able to check the accuracy of particular elements of a program, one at a time. For example, solar absorbtion by walls could be checked by simulating a windowless building in a constant temperature climate, with and without a constant solar radiation, using both the program to be tested and the reference program. Solar transmission through windows could be checked by running both programs for a building with real windows, then for a building with perfectly reflecting windows, with other conditions such that all solar radiation admitted to the building would reduce the heating load.

The advantage of using real data is that the importance of the approximations used to the program's predictions under real circumstances is correctly estimated. For example, a simple BEA computer program might use the ASHRAE Cooling Load Temperature Difference (CLTD) and Cooling Load Factor (CLF) methods to compute the time distribution of the cooling load during a typical day of weather representative of a particular month. To compare this program with an hour-by-hour BEA program using real w--' -. would provide a useful estimate the errors caused by this approximation. To test the simple program using abnormal weather conditions (such as, for example, a step change in solar radiation) would prove only what is already known, that CLTD's and CLF's have been calculated by assuming a particular time distribution of solar energy, and they are not accurate if the time distribution is different.

The major factor in the decision between the approach of using realistic weather and the approach of using special weather prepared to test individual elements of the program is the purpose of the validation. If it is intended to diagnose the faults of the BEA program being tested, the latter approach will be more useful. If it is intended only to accept a particular program as "accurate enough", or to reject those which are not, then the approach of using realistic weather and a simplified, but realistic building, is more useful.

One issue which must be considered when validating a BEA program by program comparison is which BEA program to use as the basis of comparison. A practical approach, which has been taken by the International Energy Agency (IEA), was to use several well validated and well respected BEA programs. [14] The range of results predicted by these programs for each of the test cases was then considered the "correct" range for comparison of the predictions of the programs to be verified. Of course, one would only have confidence in this approach if the previously verified BEA programs being used as a basis for comparison all predicted energy consumptions which agreed with one another.

5. SOME EXAMPLE VALIDATION PROJECTS

5.1 The IEA Evaluation Procedure

The IEA project was carried out as a joint effort under IEA Task VIII, to provide a technical basis for a quantitative BEA program evaluation procedure. In this study, five "reference codes" were selected. These were BEA programs which were known to use good thermal models and computational techniques, and which had had extensive independent validation. These programs were BLAST 3.0, DOE 2.1C, ESP, HTB2, and SERIRES. They were run for 28 different buildings and two different climates, and the results were compared.

Fig. 1 shows the annual results for nine cases involving variations of a simple building in the climate of Denver, Colorado. The lower predictions of ESP in Cases 3, 4, 9 and 10 were found to be due to the use of a different incident radiation model which puts more diffuse solar radiation in the south than the models in the other programs. This was considered a legitimate variation, since no incident radiation model generally accepted as "correct" has yet been developed. This difference between the

program results was emphasized by the nature of the test building for these four cases, which had only south-facing windows. This difference between programs disappeared when they were run using the cloudier weather of Copenhagen, Denmark. It would also be expected to disappear for real buildings with more uniform window distributions.

Fig. 2 shows the application of the reference code results to the validation of three simpler BEA programs, EBIWAN, BREDEM and ENERPASS. The heavy horizontal lines are the limits of the reference code predictions for each case. An inspection of this graph shows that the worst result is for BREDEM in Case 10. This case is a heavy building with a wide thermostat dead band. The BREDEM prediction for this building is the same as for Case 9, a light building which is identical to Case 10 in every other respect. This indicates that BREDEM does not model well the storage of solar energy in the mass of the building. Cases 3 and 4 are also different only in the weight of the building. Again, BREDEM does not distinguish between these two cases. It appears that the other two programs tested perform well for all the cases studied.

This brief review of some of the IEA work illustrates how their approach can be used not only to assess the overall accuracy of the BEA programs tested, but to get some idea of which program features may be deficient. In the next section, an approach is described which focuses more on determining the capabilities or deficiencies of particular elements of a program.

5.2 The Validation of HOTCAN 3.0

HOTCAN is a fast, easy-to-use BEA program for houses. It does one energy balance per month. We carried out a validation [13] of HOTCAN 3.0 using BLAST 3.0 as the basis for comparison. (We had already validated BLAST 3.0 against experimental data for two test houses with similar characteristics.) It should be emphasized that the errors described below, which we found in HOTCAN 3.0 were eliminated in later versions of the program.

In this study we used artificial building modifications and artificial weather so that we could not only find the deviations of HOTCAN 3.0 from BLAST 3.0, but could pinpoint their causes. We ran 56 different cases with different wall R values, window areas, window shading, allowable temperature swings, airtightness, forced ventilation, and heat recovery equipment. We used ten different weather files including stepped and sinusoidal temperatures, constant and zero wind speeds, real and zero solar radiation, and real temperatures.

Almost all these runs showed good agreement between the programs. Only three significant deviations were found. One comparison showed that HOTCAN 3.0 did not account for the reduction in heat loss due to solar heating of opaque surfaces. Fig. 3 shows the change which resulted when this deficiency was corrected. It was also found that HOTCAN 3.0 was using an obsolete expression for the utilization of internal heat gains. Due to an oversight, an improved expression had not been implemented in the program. Fig. 4 shows the comparison.

The third error appeared first as a difference in the utilization of solar gains. It was finally traced to a weakness in the HOTCAN model for dividing measured total horizontal radiation into direct and diffuse radiation. This, of course, influenced the amount of radiation calculated to fall on the windows of the house. Fig. 5 shows the deviation in the diffuse fraction which was identified.

It is interesting to note that the standard deviation of the monthly energy use predictions of HOTCAN 3.0 from BLAST 3.0 was only 28 W. If the only comparison made had been of these overall energy predictions, HOTCAN 3.0 would have received a very good rating, but only because the three errors cancelled one another for this particular building. When applied to another building, the results might have been substantially in error. This indicates the value of using artificial cases to check individual aspects of a BEA program being validated even when there is no intention to repair the program, but only to accept or reject it.

6. CONCLUSIONS

The cheapest and most certain method of validating a BEA program is comparison with analytical results. However, the range of program elements and cases which can be analyzed is limited. For those program elements and cases outside this range, the preferred method of validation is program-to-program comparison.

There are several hour-by-hour BEA programs, which have themselves been validated in some detail, to use as standards of comparison. These include BLAST 3.0, DOE 2.1C, SERIRES, ESP, and HTB2. The best alternative, if it can be afforded, is to use all these programs as the standard of comparison. One way of doing so is to use the results already obtained by the IEA [14].

Component-by-component evaluation, using artificial building descriptions and artificial weather data to focus on each program component in turn, is the best approach to comparative validation. Not only does it identify the specific problems in the program being validated, but it prevents the approval of programs whose overall energy

consumption predictions are good because their errors cancel one another.

REFERENCES

1. Alereza, T., and Hovander, L., "A Micro Evaluation", ASHRAE Journal, Vol. 27, No. 12, December, 1985.

2. Herron, D., Windingland, L., and Hittle, D., "Comparison of Building Loads Analysis and System Thermodynamics (BLAST) Computer Program Simulations and Measured Energy use for Army Buildings", Construction Engineering Research Laboratory, U.S. Army Corps. of Engineers, Interim report, CERI-IR-E-161, Champaign, IL, 1980.

3. Yuill, G. K., and Phillips, E. G., "Comparisons of BLAST Program Predictions with the Energy Consumptions of Two Buildings", ASHRAE Transactions, Vol. 84, 1, CH-81, No. 2, pp. 1200-1206, 1981.

4. Judkoff, R., Wortman, D., and Burch, J., "Measured Versus Predicted Performance of the SERI Test House: A Validation Study", SERI/TP-254-1953, presented at the National Heat Transfer Conference, Seattle, WA, July, 1983, published by Solar Energy Research Institute, Golden CO, May, 1983.

5. Yuill, G. K., "Verification of the BLAST Computer Program for Two Houses", ASHRAE Conference, Honolulu, June, 1985.

6. Yuill, G. K., and Gin, K., "Thermal Performance of a Passive Solar Low Rise Office Building", Energy Solutions for Today Conference, Ottawa, Canada, June 22-25, 1988.

7. Dumont, R. S., Lux, M. E., and Orr, H. W. 1983, "Comparison of Energy Consumption Calculations Using HOTCAN with Measured Values From Unoccupied Test Huts", Proceedings, Solar Energy Society of Canada, Inc., Annual Meeting, Windsor, Ontario, August.

8. Bauman, F., Andersson, B., Carroll, W. L., Kammerud, R., and Friedman, N. E., "Verification of BLAST by Comparison with Measurements of a Solar-Dominated Test Cell and a Thermally Massive Building", Transactions of the ASME, Journal of Solar Energy Engineering, Vol. 105, May 1983, pp. 207-216.

9. Andersson, B., Bauman, F., and Kammerud, R., "Verification of BLAST by Comparison with Direct Gain Test Cell Measurements", LBL-1-619, UC-95d, Lawrence Berkeley Laboratory, Berkeley, CA, November, 1980.

10. Bland, B. H., and Bloomfield, D. P., "Validation of Conduction Algorithms in Dynamic Thermal Models", 5th CIB, Bath, 1986, pp. 22-35.

11. Bland, B. H., "Experience With Analytical Tests for the Validation of Dynamic Thermal Models", USER 1 Conference, Ostend, September, 1988.

12. Yuill, G. K., "Design of Test Procedures for BESA", Report to the National Research Council by G. K. Yuill and Associates Ltd., December 8, 1987.

13. Yuill, G. K., and Wray, C. P., "An Approach to the Verification of Simple Building Energy Analysis Computer Programs", ASHRAE Conference, New York, January, 1987.

14. Judkoff, R., et Al., "International Energy Agency Design Tool Evaluation Procedure", ASES Annual Meeting, Cambridge, Massachusetts, U.S.A., June 20-24, 1988.

15. Yuill, G. K., and Wray, C. P., "Verification of a Microcomputer Program Implementing the Mitalas Below Grade Heat Loss Model", ASHRAE Conference, New York, January, 1987.

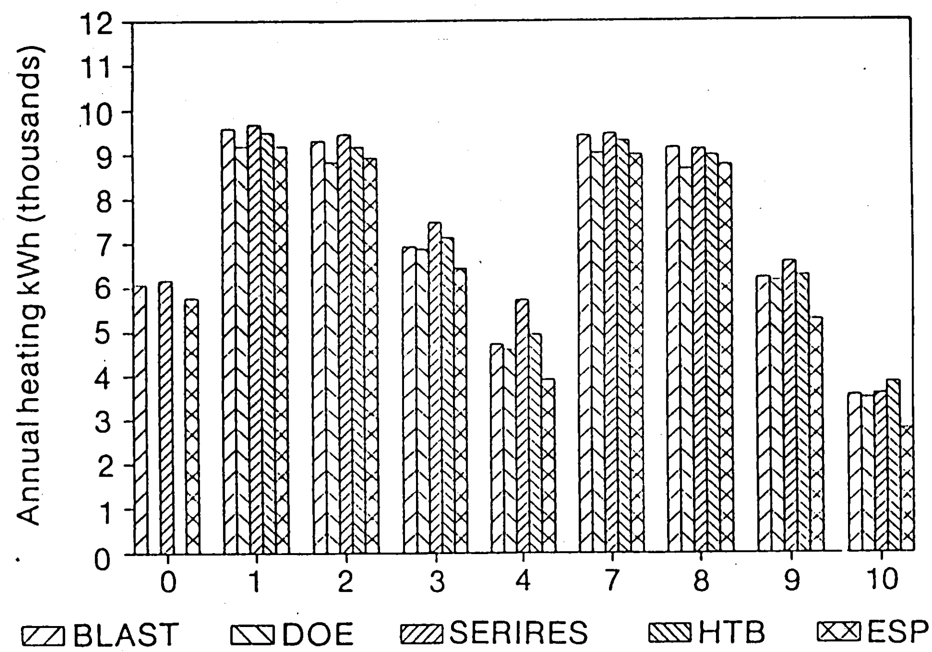


Fig. 1 - IEA Reference Codes Cases 0-10 (Denver TMY)

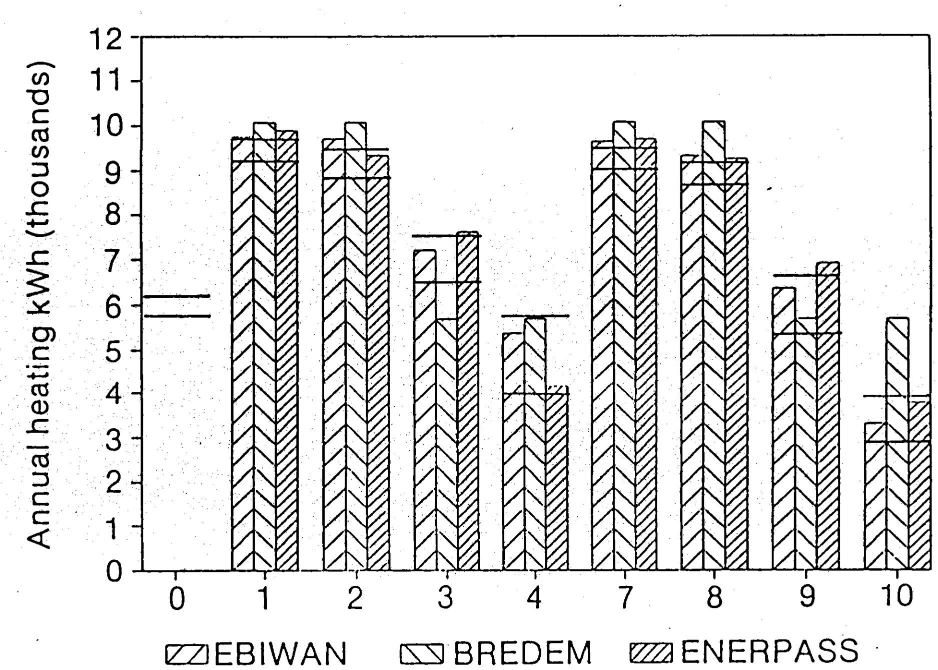


Fig. 2 - IEA Design Tool Examples (Denver TMY cases 0-10)

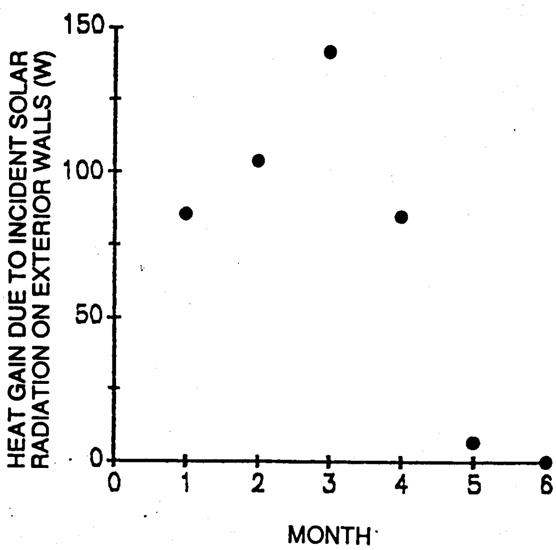


Fig. 3 - Effect of exterior surface solar heating - monthly average total heat loss rate change due to addition of solar radiation. Exterior wall: thermal resistance = 2.53 m^2K/W, surface solar absorptivity = 0.7

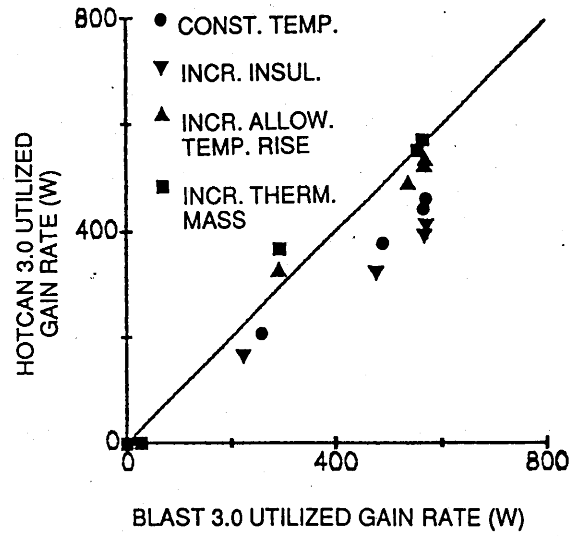


Fig. 4 - Comparison of HOTCAN 3.0 and BLAST 3.0 monthly average utilized internal gain rates. Available internal gain rate: 583 W

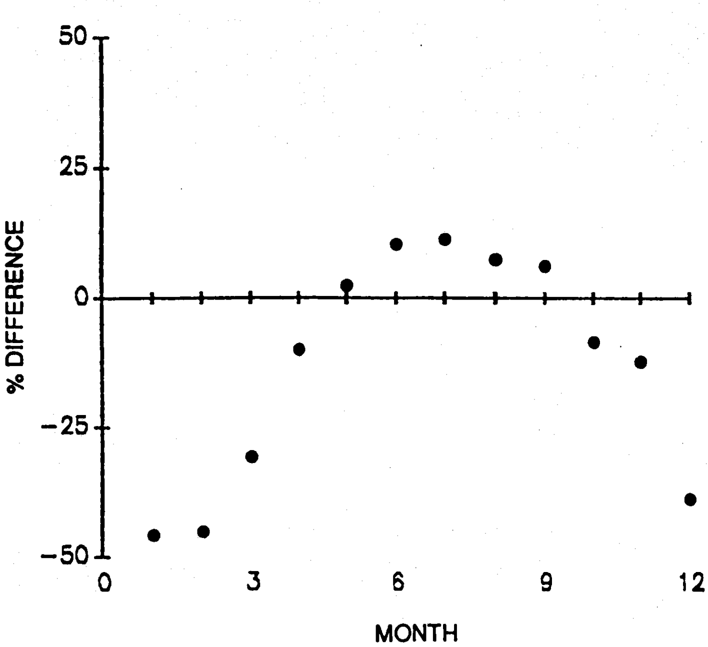


Fig. 5 - Percentage difference between HOTCAN 3.0 and BLAST 3.0 fractions of monthly average horizontal diffuse solar radiation

Optimizing Inventory of Critical and Expensive Spares Through Simulation.

Mr. Joseph S. Tsui

Syncrude Canada Ltd.
P.O. Bag 4009, M.D. 4115
Fort McMurray, Alberta
Canada T9h 3L1

Introduction

The management of critical and expensive spares eludes conventional techniques that assume known usage, established supply performance, and known stockout impact. Often, uncertainties in these areas are the rule rather than the exceptions. In capital intensive industries where multiple stage processes depend on the reliable performance of certain critical and expensive equipment, computer simulation offers a practical approach to manage the inventory of such spares. When the process is simulated along with component and supplier performance, economic impact to the overall operation at different stock levels can be evaluated, As a result, both the risk of stockout and total operating cost can be optimized. This paper discusses the elements to be considered in this approach and how it can be applied through illustrating a successful model developed in Syncrude Canada - the world's largest oilsands mining and processing plant.

Management Decision Criteria and Modelling Parameters.

This approach concerns only critical and expensive spares. Critical means that the component can potentially affect the total operation when failed unexpectedly. Expensive means the cost of acquiring and holding components of this type significantly impacts on the overall operating cost. Usually, they are the rare parts where careful rationalization is important to hold the right number of the right kind. Like other management decisions, optimization is achieved at a stock level when the probable economic cost to the company is the least at an acceptable level of risk. This implies therefore that the following information is necessary for objective, optimal decisions:

1. The expected risk of a stockout when a part fails at various intended levels of stock.
2. The expected consequences on production in quantifiable terms during a stockout. - Penalty Cost.
3. The total investment at various level of stock - Holding Cost.
4. The aggregate expected economic cost to the operation including financial and tax implications.

These questions focus on two areas for investigation. First, the actual production impact when a part fails and all probable actions to recover and minimize the impact. Secondly, how to measure the impact where multiple parts and multiple process stages are involved. In most capital intensive industries, the impact of a particular part failure varies dynamically with changing operating conditions. Some key factors that have to be considered include:

1. Status of the spares inventory and condition of the spares.

2. The extent of damage on the productive capacity of the equipment or process in question.
3. The criticality of the equipment or process as part of the overall operation.
4. The repairability of the component, the probable duration / cost of the repair and the condition of the part after repair.
5. Normal supply sources and probable lead times for off-shelf and custom-made alternatives.
6. Extraordinary supply sources that include 'borrowing' from a parallel process or from a similar outside operator.
7. The timing of the failure in relation to production and maintenance plans. On one hand, the equipment may be assigned top production priority when it fails, on the other hand, it may fail just before a scheduled part changeout program.
8. The extent of production storage buffers between equipment or process stages.
9. The upstream supply of production and downstream demand variations.
10. Contingent production alternatives and associated costs.

As evidenced from the above, the practically limitless combinations of decisions and events that may change the impact of a part failure greatly complicates any pure mathematical solution. They strongly suggest that relevant simulation combined with statistical treatment of results is a more practical approach.

To measure the economic impact of a particular failure, the following have to be considered:

1. A reference production rate of the equipment or process has to be established. Usually, the short term planned rate is preferred over the longer budgeted rate.
2. The concept of a planning horizon needs to be established beyond which any production shortfall observed may not be attributed to the failed part in question.
3. The interaction of parallel processes have to be understood. For instance, how flexible is one process able to make up the shortfall in the other process and if the processes can be 'crossed' to produce the final product.
4. The operating philosophy regarding individual stages of the overall process needs to be clarified. For instance, buffer storages between process stages may be designed to handle only certain production contingencies and are not intended to absorb other shortfalls.
5. Interaction with and treatment of scheduled production stoppages such as Preventive Maintenance activities and unexpected shortfalls other than the specific part failure have to be defined in a manner consistent with the practical expectations of the operation.

There are probably three main design characteristics that are essential for this approach:

- Realistic - In most large operations, there are standard procedures for normal operation but there are also contingent measures available to minimize unexpected critical events. Failure of a critical equipment would likely trigger these emergency type activities and therefore should be incorporated lest penalty cost would be unrealistically overstated.
- Practical - Model input should be formatted in a manner familiar to the personnel involved such as maintenance planners, purchaser etc. For instance, when estimating part failure frequency, terms like most probable, maximum and minimum need to be referenced to the percentile point of the distribution. Model results also should be easily understood and readily support decision making.
- Flexible - In order to stay relevant. model should be structured such that it is easily changed to reflect changes in the operation and equipment conditions.

Simulation Process

For each stock level of the critical spares investigated, the model simulates a number of years of the entire operation. The equipment or process operates according to the best estimated distributions along

with the multiple parts being studied. At each statistically generated part failure incidence, all decisions and activities are simulated and the best estimated impact on production is captured. Elaborate procedures are used to ensure a fair allocation of impact for multiple concurrent failures. After a statistically significant period, all failure incidences of each part are analysed to determine the expected risk of stockout. The production impact of all part failures are converted in economic terms while considering the specific financial and tax policies in place. The process is then repeated for other stock levels. Finally, the stockout risk and cost profiles for all investigated stock levels are constructed and the optimum level is recommended using simple graphical representation.

As an illustration, the following is a brief description of the processes simulated in the Syncrude Model.

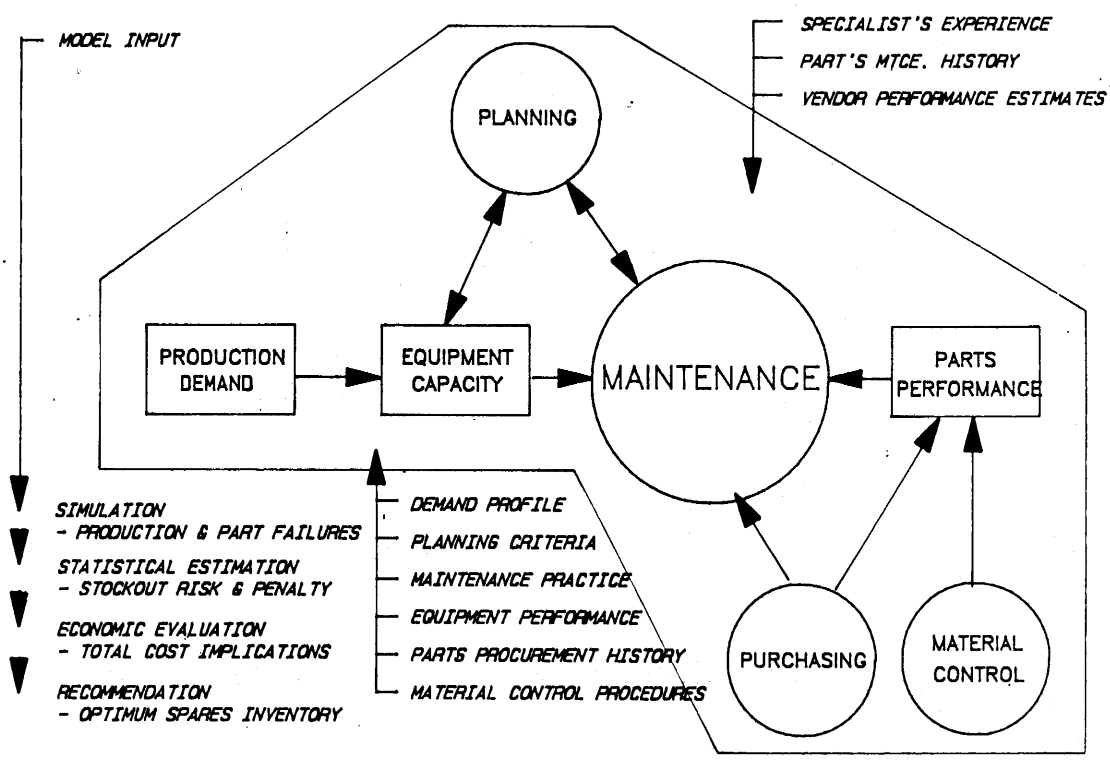


FIG. 1 : SIMULATION PROCESS OVERVIEW

The processes involved are mainly mining and metal extraction. As such, they are characterized by human intervention which can quickly react to changes in operating environment. Mine equipment capacity is designed to meet Extraction Plant demand. This production capacity is affected by the performance of the critical parts of the equipment and their availability for replacement when failed. Both Material Control and Procurement functions aim at securing these parts at the proper time, from the proper source and normally at the lowest cost. Maintenance both react and proact to the incidences of part failures. Activities are geared to ensure timely maintenance of these parts to avoid unexpected failures and to minimize their impact by re-arranging work priorities, quick temporary fix-ups, and expediting repair of the parts, etc.. Planning activities provide directions to Operations to achieve the proper level of production from the proper configuration of equipment. This is achieved partially by ensuring adequate maintenance opportunities to maximize total equipment availability. At times of part failure, Planning initiates actions to minimize production impact by altering equipment priorities / configuration and initiating contingent production capacities. The basic philosophy of this operation is to meet Extraction process demand irrespective of downstream buffer storage. Alternative production capacities at increasing costs are triggered at increasing levels of impact severity to meet the demand.

On the one hand, the model is driven by input that describes the inter-relationships of the equipment and operational criteria such as:

1. Extraction demand of oilsand represented by historical production distributions modified with current policies.

2. Mine equipment performance distributions incorporating seasonal factors.
3. Planning decision criteria for equipment configuration and contingent production capacities.
4. Maintenance schedules and practices represented by historical distributions and current budget.
5. Procurement and Material Control policies and procedures.

On the other hand, relevant information describing the performance of the equipment spares are input into the model from the following sources:

- Maintenance specialists' experience regarding useful life and repairability of the parts in terms of probabilistic estimates.
- Actual maintenance history of the parts.
- Vendor performance for the parts including delivery time, custom-made time and on-shelf probabilities.

The Syncrude Model is structured in modules to provide maximum flexibility. Simulation Language for Alternative Modelling (SLAM) is chosen as the main programming language because of its flexibility in simulating in a number of different modes and the ease in interfacing between them:

- Networking for discreet equipment performance patterns.
- Continuous for buffer and intermediate production storages.
- Discreet for capturing decision and production impact logic.

Statistical Analysis System language (SAS) is used for statistical treatment of the model results.

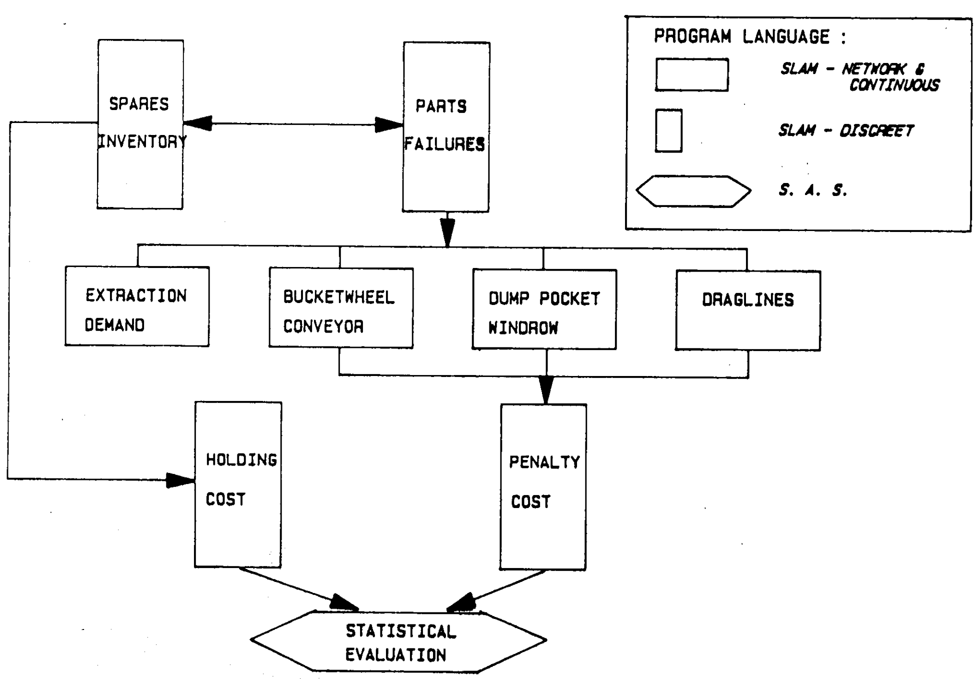


FIG. 2 : MODULAR STRUCTURE OF MODEL

Model output

Output from the model should be simple yet sufficient to support rational decision making. The normal output from the Syncrude Model consists only of two graphs for each critical part investigated. As illustrated in Figure 3. and Figure 4., they show the profile of stockout risk and the aggregate cost curves corresponding to the different stock levels. The risk of stockout is simply defined as the probability of a stockout for the next unexpected failure of the part.

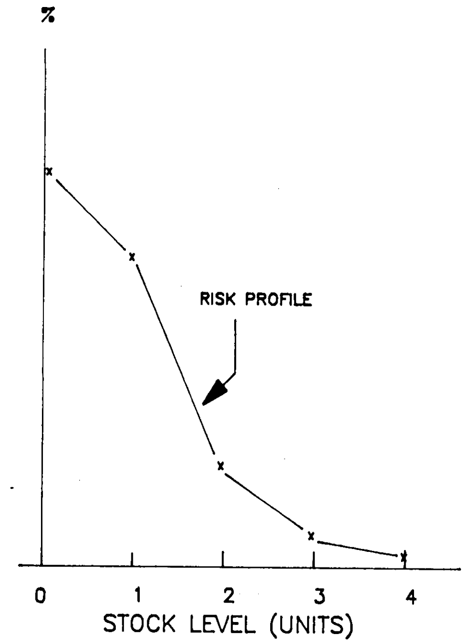


Fig.3 Risk of Stockout VS Stock Level

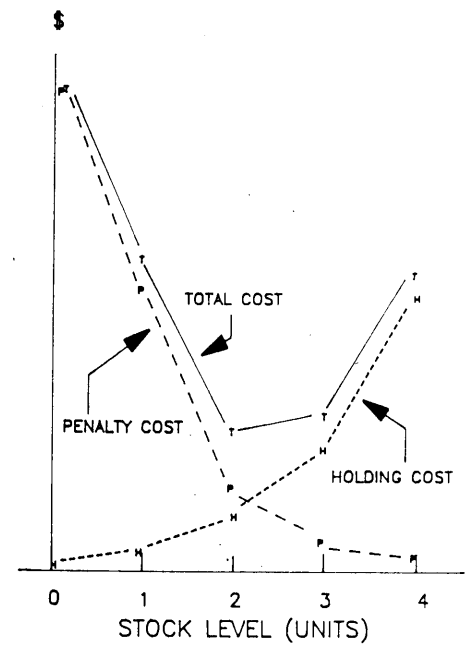


Fig.4 Expected Cost VS Stock Level

The typical risk profile experienced for Syncrudes critical parts consists of three fairly well defined phases. As illustrated in Figure 5, there is an initial phase of inertia from the point of not stocking to some minimum stock level. Stockout risk behavior is unstable and is not significantly reduced in this phase. This is followed by a phase of definite steep decline of stockout risk for a narrow range of increase. This is the phase where maximum marginal economic return would be derived. Finally, there is the phase of diminishing return in which rather little reduction in stockout risk is associated with a relatively large increase in stock. The Penalty Cost curve also follows a similar pattern albeit with steeper gradient of the curve in each phase due to the magnifying effect of probable concurrent failures.

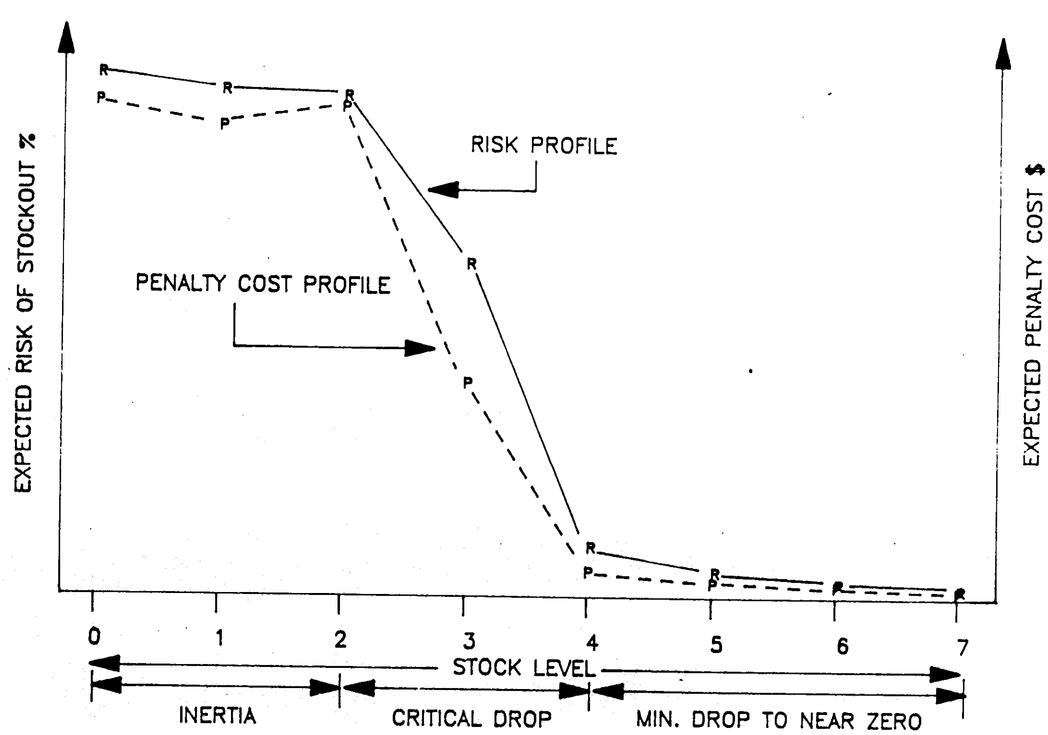


FIG.5 : GENERAL BEHAVIOR OF CRITICAL PARTS

The optimum point of stocking occurs normally at the minimum point of the Total Cost curve. However, there may be situations where the optimum region of the Total Cost curve is fairly flat and management deliberation is required based on the corresponding stockout risk behavior and other non-economic factors. Invariably, with multiple similar parts in operation, the optimum stock level is at a point much below the total number of the parts operating in the field. In most cases, even the point of near zero risk corresponds to a stock level much below the number operating. Investment beyond that level is basically a waste of resource.

Model reliability and acceptance.

A common problem with the use of computer simulation is that it tends to be a 'black box' tool. Important users and management may not fully understand the logic of the simulation process and therefore acceptance of the model results would be difficult. Present development in caricature representation helps in communicating the simulation process. However, with highly involved simulation like the Syncrude Spares Model, it is paramount that a proper strategy is in place to ensure model reliability and acceptance.

Some of the activities that can be considered include:

1. Reviewing model logic, assumptions and algorithms at each stage of development and approval by all concerned personnel, for instance, after each module.
2. Comparison of model generated operation statistics to historical data to ensure conformance.
3. Test runs using familiar parts to ensure that results reflect actual experience.
4. Testing for sensitivity to changes in part performance and operating conditions to ensure that model reflects overall experience.

As an illustration, Figure 6 and Figure 7 show the typical comparison between the model generated operating statistics and historical records for the Syncrude Model.

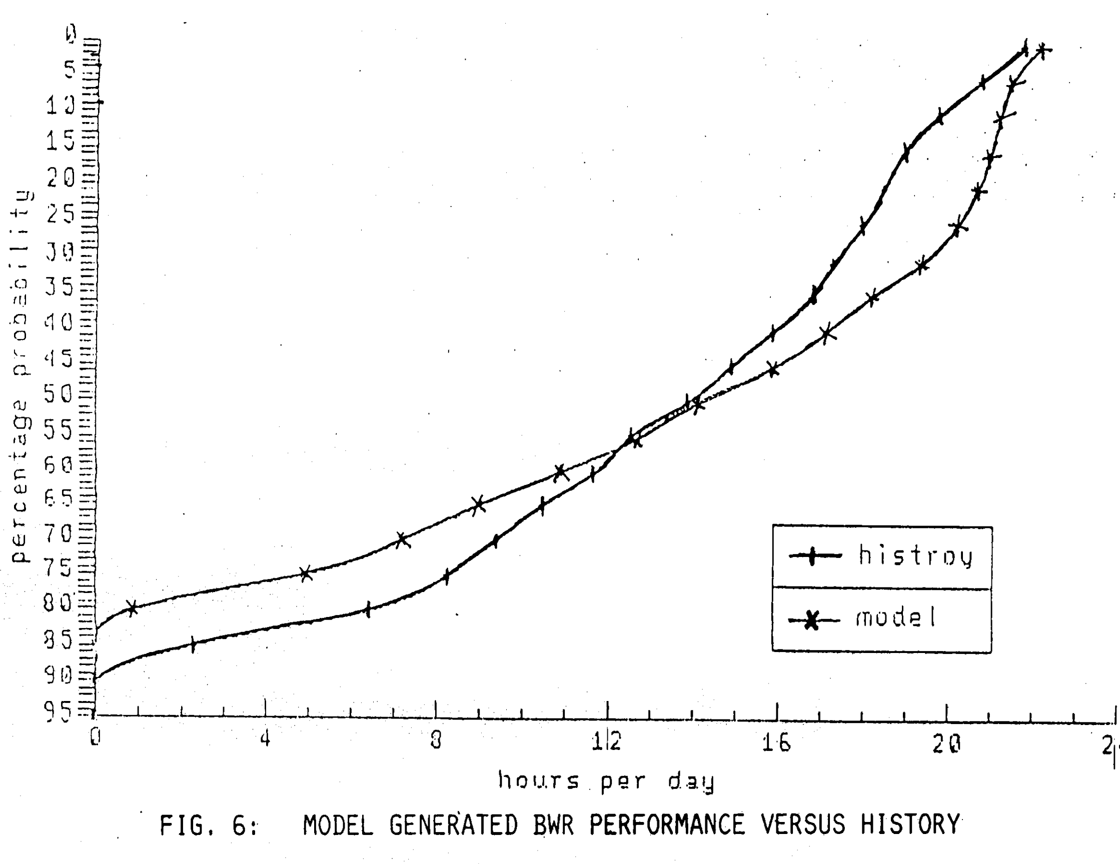


FIG. 6: MODEL GENERATED BWR PERFORMANCE VERSUS HISTORY

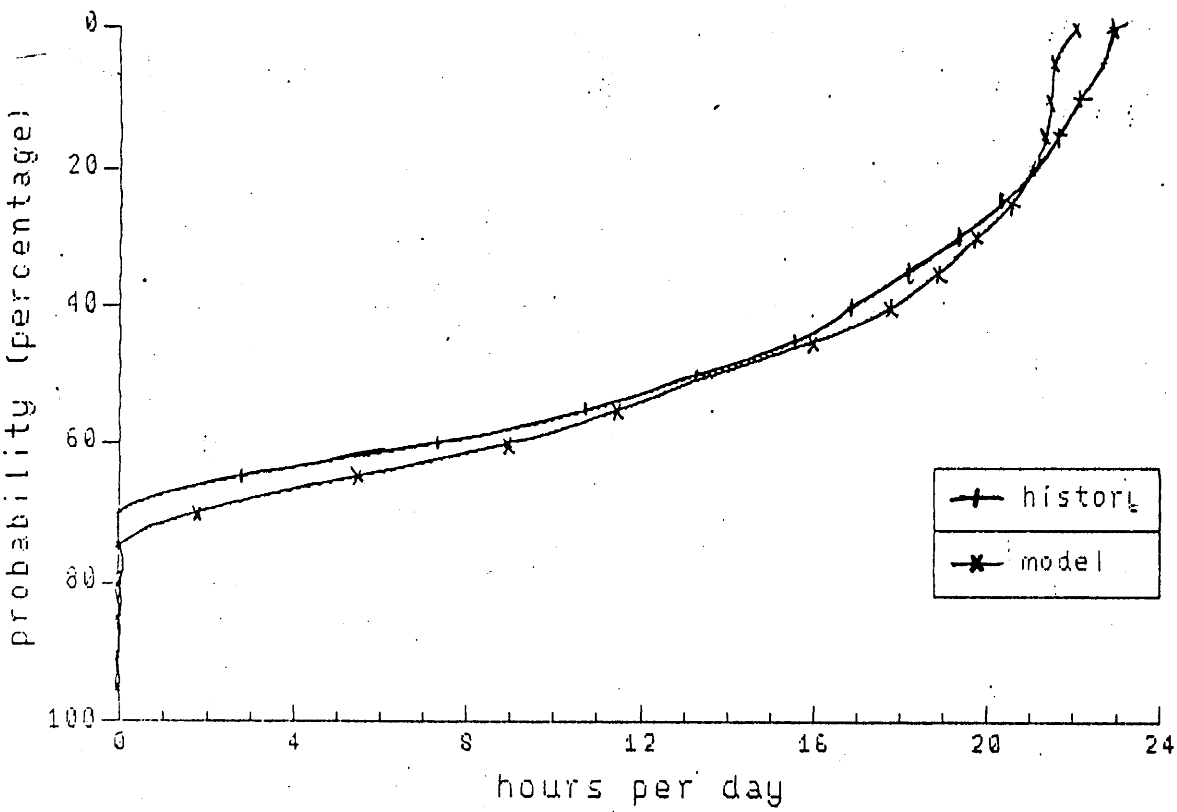


FIG. 7: MODEL GENERATED DRAGLINE PERFORMANCE VERSUS HISTORY

The minor deviation of the model distributions from the historical ones can be explained by a greater averaging of the model data.

Sensitivity tests are a means of gaining insight into the reliability and consistency of the model. A number of meaningful tests can be constructed. As an example, for a typical critical spare examined by the Syncrude Model, Table 1 and Table 2 illustrate the separate effects of varying the expected mean time between failures and the normal supplier lead time respectively on stockout risk and cost behavior of the part.

TABLE I

SENSITIVITY TEST BY VARYING ESTIMATES
ON TIME BETWEEN FAILURES
HOIST INTERMEDIATE GEAR
TOTAL COST VARIATIONS ($100)/RISK % VARIATION

S.L.	E x 80%	E x 90%	Est.(E)	E x 110%	E x 120%
1	461/39	385/41	88/32	90/20	271/27
2	170/11	$\boxed{35/9}$	$\boxed{40/4}$	$\boxed{40/0}$	$\boxed{40/0}$
3	$\boxed{61/0}$	63/0	64/0	64/0	67/0
4	87/0	90/0	88/0	89/0	90/0
5	112/0	116/0	116/0	115/0	116/0

S.L. - Stock Level

TABLE II

SENSITIVITY TEST BY VARYING NORMAL SUPPLIER
LEAD TIME ESTIMATES
HOIST INTERMEDIATE GEAR
TOTAL COST VARIATIONS ($100)/RISK % VARIATION

S.L.	E x 80%	E x 90%	Est.(E)	E x 110%	E x 120%
1	399/30	370/36	88/32	210/32	258/30
2	$\boxed{39/0}$	$\boxed{39/0}$	$\boxed{40/4}$	$\boxed{64/6}$	244/17
3	64/0	63/0	64/0	78/3	$\boxed{61/0}$
4	89/0	88/0	88/0	87/0	87/0
5	116/0	116/0	116/0	115/0	116/0

S.L. - Stock Level

Total cost and risk percentage are shown against each stock level. the columns are model results for the estimated parameters factored by various percentages with the optimum levels highlighted in the boxes. As shown,the model recommended levels are fairly insensitive to minor changes in these two parameters. The variations are more significant across the stock levels than across the factored estimates. In actual production, since a large number of factors are involved in genaerating the net impact on production when a part fails, it is expected that minor changes in these parameters can be absorbed readily with only minimal consequences.

Table 3 below is another example of model sensitivity testing for internal logic consistency.

TABLE III

SENSITIVITY TEST BY
RANDOM NUMBER STREAMS
HOIST INTERMEDIATE GEAR
TOTAL COST VARIATIONS ($100)/RISK % VARIATION

S.L.	SET 1	SET 2	SET 3	SET 4	MEAN	S.D.
1	188/30	529/32	329/18	88/32	263/28	190/6.7
2	$\boxed{39/11}$	$\boxed{57/7}$	$\boxed{40/4}$	$\boxed{40/4}$	41/6.5	9/3.3
3	63/0	61/0	62/0	64/0	62/0	2/0
4	90/0	88/0	89/0	88/0	89/0	1/0
5	115/0	113/0	114/0	116/0	115/0	1/0

S.L. - Stock Level

The model simulates the operation for a statistically significant period of time to derive statistics on part failure impact. If the simulated representation is reasonably correct, the model should converge to a set of consistent result after the period. By changing the random number seeds representing the different operating event sequences, this consistency can be tested. As shown in Table 3, consistent optimum stock levels result in the Syncrude Model.

Model Benefit.

Many recent propositions in managing critical and expensive equipment spares have either neglected or taken for granted the key issues relating to this type of spares - uncertainties surrounding part performance and production impact. This approach addresses the central issues directly through applying the advanced technology of computer simulation. Economic benefits can be significant for any capital intensive operation. For Syncrude, the model is a means of optimizing over $30 million of investment and minimizing both the risk and impact of stockout penalties. From a small sample of 18 parts investigated initially, a net reduction of over 15% dollar investment results, more importantly, investment can now be made on the right parts consistently.

THE ROLE OF SMALL ENERGY RESOURCES IN RURAL AREAS OF AFRICA THE IMPORTANCE OF ENERGY POLICY AND IMPLEMENTATION

Antonio Naviglio
Director, UNITAR/UNDP Centre on Small Energy Resources
Via Panama, 12 - 00198 Rome, Italy

ABSTRACT

Energy is a key factor for overall development and is vital for improving rural living standards. Africa is endowed with substantial and varied energy resources. Yet, the total energy needs in Africa are primarily met from traditional woodfuels, petroleum fuels and animate power. Woodfuels and animate power are the main resources for some African countries and for most rural African areas. The problems associated with the fuelwood crisis and with the many African countries' dependence on oil imports calls for alternative sources of energy. In rural areas, these sources should meet basic needs such as lighting and cooking, and should allow the development of productive activities. The rational choice between various small energy resources in a given situation would be greatly facilitated by the existence of national energy policies and programmes. The lack of such a policy framework in the majority of African countries acts as a serious barrier to the diffusion of technically and economically viable energy technologies. National energy planning, within which the most appropriate energy technologies can be chosen, depends on political will and on a good information base. To this end, a clearly defined framework is essential in developing a systematic approach to energy planning.

1. INTRODUCTION

The UNITAR/UNDP Centre on Small Energy Resources (Centre) was established in Rome, Italy, in 1984, to promote the development of small energy resources (SER) with a special focus on rural areas of developing countries, where the energy factor is recognized as an essential element of overall development and where it is of fundamental importance to the survival of the poor and most disadvantaged groups.

Small energy resources are understood to include: shallow oil and gas reservoirs, small coal and lignite deposits, mini-hydro, biomass,

small-scale geothermal plants, solar and wind and, with the exception of nuclear energy, all types of energy resources that can be developed on a small-scale basis. Energy-saving technological processes and equipment, suitable for small-scale installations, are also included.

To facilitate the exchange of information on small energy resources and related technologies and the development of their exploitation in rural areas of Africa, in 1987 the UNITAR/UNDP Centre on Small Energy Resources set up a "Promotional Programme on Small Energy Resources for Rural Africa". In this context, the Centre provides information on SER exploitation to African countries; it organizes international meetings and conferences to analyse specific issues with the aim of overcoming present constraints to the rational use of local energy resources; it provides technical training courses to facilitate the creation of local manufacturing industries specialized in energy equipment. This Promotional Programme also benefits from the other Programmes of the Centre, namely the publication of a Newsletter which discusses the application of different technologies and presents case studies of particular projects.

As part of the aforesaid Promotional Programme, the Centre organized an Experts' Group Meeting on Energy for Rural Areas of Africa, held in Rome in March 1988.

The Meeting had two overall aims:

1) to identify the most important issues concerning the proper use of energy resources in rural Africa and, in particular, what the priorities should be for every aspect of national energy planning, whether technological, financial, political, socio-economic or environmental. Linked to this was the identification of the main constraints to the rational use and development of SER in rural Africa and ways of overcoming them;

2) to put forward a set of proposals regarding the future activities and role of the Centre, specifically follow-up actions to be undertaken within the framework of its Promotional Programme on Small Energy Resources for Rural Africa.

The Centre selected and invited a number of participants directly. In addition, it requested other UN organizations to contribute to the Meeting by identifying high level experts working within their structures. Finally, in order to obtain the viewpoint of other entities with particular expertise in technical aspects of SER exploitation and in project implementation, the Centre approached international research centres, donor agencies and other UN agencies to designate experts in these subjects. This procedure was followed so as to best fulfill the Meeting's aims and to ensure a thorough assessment of all the implications of energy exploitation in the rural areas of Africa.

During the Meeting the experts related their own or their organizations' experiences in the implementation of various SER projects.

One of the major issues which emerged during the Meeting was the

necessity for the establishment and implementation of energy policies and programmes, explicitly including the rural sector.

2. THE NEED FOR ENERGY POLICY

Energy is one of the key factors for agricultural, industrial, social and economic development. African countries are endowed with substantial and varied energy resources. Yet, the total energy needs in Africa are primarily met from traditional woodfuels, petroleum fuels and from animate power (1).

The most pressing problem, especially in rural areas, relates to the unsustainable and inefficient use of biomass resources, in particular in the form of wood for fuel. The indiscriminate cutting of trees and forests for wood fuel contributes to deforestation and eventually to desertification, siltation of water reservoirs, flooding, and even higher scarcity of wood fuels (2).

Another problem in many African countries is their dependence on imported oil. At present, a significant amount of the total commercial energy used in the rural areas in African countries is accounted for by hydrocarbon energy, i.e. conventional fossil fuels. The bulk of this is in the form of imported oil. The need to reduce this heavy dependence on oil imports calls for increased energy self-sufficiency in African countries. In this respect, local small energy resources have a potential role to play in helping countries to achieve greater energy self-sufficiency.

There are many motivations for the desire for energy self-sufficiency, the two primary ones being savings to the economy and assured supply. Most African countries currently spend a significant portion of their national budgets on the importation of oil. The goal of an assured energy supply is common to all countries. The history of dislocations in the world energy markets provides the incentive to develop indigenous energy resources and to avoid the serious consequences of interruptions in energy supply in the agricultural and industrial sectors, especially in rural areas.

A major problem impeding some African countries from expanding their resource base is the lack of adequate knowledge of their energy resource endowments, particularly of potential new and renewable forms of energy such as solar, biomass, biogas, hydropower and wind. Other African countries are well-endowed with, and have the potential for developing these new and renewable sources of energy; however, most of these potential resources have either not been developed at all or are being used in inefficient ways.

For example, it is estimated that about 30 per cent of the world's hydroelectric power potential is located in Africa; in spite of the efforts being made to develop other new and renewable sources of energy, hydropower remains the major renewable source of energy in African countries, exploitable for the production of mechanical and electric power. Nevertheless, only about 1 percent of the hydroelectric potential in Africa has been developed; very often, the distance between the

potential production sites and the demand barycentres has behaved as the barrier for the development. but also many other reasons have contributed to the same output. The underexploitation of hydropower not only for large-scale projects. but mainly for small and mini-hydropower plants especially in rural areas, has led to a heavy limitation of availability of electric power, whose role is never enough stressed in improving the living standard and in allowing industrial and agroindustrial development.

Biomass is an important source of energy in the world and is a major source of energy in rural areas in many African countries. This is mainly in the form of wood for fuel which has, due to its unmanaged and unbalanced utilization, led to deforestation and soil erosion in some countries. For full advantage to be gained from biomass energy, African countries need to carry out more research and development on all aspects of the subject, from improved biomass resource management through new conversion technologies to more efficient end-uses for both domestic as well as for industrial purposes. At the same time, account needs to be taken of the fact that biomass resources have many competing uses. Therefore, an integrated and balanced approach must be adopted in line with the particular needs of rural areas in individual countries.

Most African countries, owing to their geographical location, have abundant solar radiation. This form of energy has traditionally been used in the agricultural sector for cropdrying. There is, however, a wider application of solar energy for a variety of industrial uses such as bottle washing, sanitary uses and boiling, which could be of special relevance to rural industrialization. Another important use of solar energy is the direct production of electric power through photovoltaic cells for limited electric productions serving telecommunications, food and medicine preservation and lighting. This is a new technology which, in the future, could be an important renewable source of energy, particularly for rural remote areas (3).

However, a major prerequisite which is necessary in order for African countries to broaden their resource base (to utilize these and other new and renewable sources of energy and other non renewable small energy resources) and to develop the exploitation of local energy resources to the optimum, thereby increasing their energy self-sufficiency, is the formulation and implementation of a rational and coherent energy policy; such a policy is lacking in a majority of African countries.

The lack of such a policy is largely due to the dramatic need of a suitable data base for each major component of such a policy. Only a few energy planners are aware of the reasons for current patterns of energy use and their consumption (4).

This lack of coordination and integrated activities in the frame of a global development planning generally means that no specific organization exists with a recognized role and responsibility for coordination and development of energy supply and consumption systems in rural areas. This is significant in that such a situation may increase or compound the energy problem as it leaves room for the intervention of various institutes and agencies wth no experience or direct interest in

the energy sector itself.

In fact it is rather difficult to approach and deal with the energy problem in rural areas where there is a lack of central information and activities coordination. In effect, most developing countries have already produced many efforts in the energy sector and many projects are still underway; in parallel, many resources, both economic and human, have already been spent but no lasting effects have been attained (5).

Energy policy and planning is particularly crucial now as the energy situation of the African countries is at a stage of possible transition: moving away from dependence on imported energy and its financial burden, and moving towards increasing the use of indigenous energy sources and improving energy management, especially in the rural sector. This transition requires a careful examination of the complex policy options, priorities and associated issues and the formulation of clear and purposeful plans and actions. This difficult task of identifying options, establishing priorities, and translating policies into concrete action is often a major constraint in many African countries.

3. ASPECTS TO BE CONSIDERED IN ENERGY POLICY FORMULATION

African countries obviously represent a very wide variety of geographical, economical and social conditions leading to very different energy situations. It is therefore clear that only site specific considerations permit the identification of particular solutions to energy demand problems and to policies integrating energy supply and utilization patterns with overall economic development.

The woodfuel crisis, for example, cannot be analyzed or resolved through global and regional analysis and policy action: the problems are inherently local and site specific. Consequently, any policy intervention needs to be formulated in this context.

In fact, in most countries, the urban and rural woodfuel situations are sufficiently different to warrant completely different analyses and policy interventions. In the rural areas, the woodfuel crisis is essentially just the tip of a much larger iceberg, which is the underdevelopment and neglect of rural areas compared to the urban ones. Often, the woodfuel crisis identified by outside experts does not seem to be perceived by local people, mostly because they have other priorities, and perhaps much greater problems than fuelwood.

Thus, the most important first step in policy formulation is to find out as much information as possible about the specific, local situation. This means, with specific reference to the wood fuel crisis, that some level of knowledge about all the biomass supply and demand flows, the nature of the monetary and non-monetary biomass markets, as well as some knowledge about the full economic costs of conventional fuel strategies versus dependence on locally produced biomass resources is required (2).

It is thus evident that the exact nature of policy intervention will be different from country to country, and even from area to area.

It follows that any policy formation will have to be based on site-specific considerations.

In addition, certain general issues can be identified, which need to be considered when developing energy programmes and strategies (6):

- There is a gap between agricultural and rural development plans and energy plans which needs to be bridged;

- Rural energy programmes need to be effectively incorporated into global energy development plans and into rural and agriculture development planning;

- A clear perception and definition needs to be developed regarding the commercial or non-commercial character of energy resources, such as fuelwood and charcoal, as this strongly affects the overall energy decision-making process;

- The rural urban inter-relationships regarding fuelwood, charcoal and agricultural residue utilization, including price and commercialization policies need to be better understood;

- If it is accepted that in the rural sector energy requirements are high although energy demand is low, how can renewable and conventional energy sources be geared towards their fulfillment?;

- Few countries have fully evaluated their indigenous energy resources, although most are aware of the most promising ones and of the areas with the highest potential;

- Few cases exist of efforts to assess the energy requirement of sectoral development plans;

- Most countries have research teams active in various energy development fields although the majority are weak, receive little support from governments and, in general, are not integrated nto national development efforts;

- Few countries have developed price policies or commercialization strategies for decentralized, small-scale energy equipment.

- Many examples exist of demonstration projects, supported by bilateral and multilateral institutions, which have failed to promote widespread utilization of renewable energy systems, due to weaknesses and misconceptions in project design and implementation.

A consideration of these general issues should be made in in the process of developing rational, coherent energy policies and programmes. Furthermore, it must be recognized that the development and implementation of such policies is an essential step towards the notion of sustainable energy development.

4. CONCLUSIONS EMERGING FROM THE EXPERTS' GROUP MEETING REGARDING ENERGY POLICY

Several conclusions regarding energy policy emerged from the discussions held during the Experts' Group Meeting on Energy for Rural Areas of Africa. The following is a summary of these conclusions.

One of the main problems existing to the rational use of local small energy resources in rural areas of Africa as identified during the Meeting is the lack of a policy framework: There is often a lack of clearly articulated and coherent energy policy. There is thus a failure to establish the necessary environment and framework which would foster the wider application of SER technologies and allow them to live up to their full potential.

It was also recognized that many governments and donor countries do not give sufficient priority to the rural sector in Africa and to rural energy in particular. Urban centres are often favoured at the expense of rural dwellers, and conventional energy sources are often favoured while new and renewable sources of energy are discriminated against. Conversely, instances of overemphasis given to new and renewable sources of energy exist, which have fired the possibility of the development and use of these technologies.

In addition, it was noted that there is a generally weak institutional capacity for energy planning and policy making. The problem runs from the top, where the Ministries responsible for energy planning and policy making lack resources (both human and financial), to the village level, where there is a serious lack of qualified manpower.

Furthermore, there is a lack of a comprehensive data-base on energy resources available nationally and on precise local and national needs as well as of an analysis of current patterns of energy use and their consequences, which is necessary for the development of effective policies and programmes.

The participants to the Experts' Grop Meeting stressed that the rational choice between various small energy resources in a given situation would be greatly facilitated by the existence of national energy policies and programmes. The lack of such a policy framework in the majority of African countries acts as a serious barrier to the diffusion of technically and economically viable energy technologies. National energy planning, within which the most appropriate energy technologies can be chosen, depends on political will and on a good information base. The experts noted a frequent lack of both of these elements, and the problem is exasperated by the aforesaid tendency to favour the urban population over the rural one. The rural sector must be explicitly incorporated in the national energy policy.

The experts also pointed out that energy strategy must be integrated into overall development plans. Energy cannot be seen in isolation, it is but one aspect of development. Energy is vital for improving rural living standards, which are now being seriously eroded due to the shortage of fuelwood in many areas. Alternative sources of energy are required to meet basic needs such as lighting and cooking and to allow the development of productive activities in agricultural areas.

5. A PROPOSED FRAMEWORK FOR ENERGY PLANNING

Effective management of the energy sector must occur if African countries are going to be able to expand their domestic energy supplies and improve the efficiency of energy use in order to meet future needs. Effective management of the energy sector calls for the formulation of a comprehensive national energy plan and for its effective implementation.

It is clear that such a comprehensive approach needs a framework in which energy is linked with the economic plans, programmes and policies at the macro- or national level on the one hand, and with the micro-level, area-based rural development programmes, on the other.

In this respect, the Food and Agriculture Organisation of the United Nations (FAO) (7) has identified seven steps to the preparation of area-based, micro-level integrated rural energy plans, here referred as a possible framework. These steps include:

i) **Selection of the Area:** The unit of micro-level planning has to be decided after taking into account the broad economic and administrative characterstics of the country. The size of this micro-planning unit should be big enough to bring out clearly the interrelationship between development programmes and energy needs, as well as to justify the building up of a decentralized data base for planning purposes.

ii) **Energy Surveys:** Rural energy surveys through which the existing pattern of energy consumption for different end-uses for domestic consumption and productive activities are determined for various energy resources and options, should be carried out. The survey format should be modified to suit the specific conditions of the micro-region being surveyed for an integrated plan.

iii) **Energy Demand Projections:** Demand projections for energy should be made for subsistence level needs (i.e. cooking, heating and lighting) and for the economic development of the area. Subsistence-level needs can be projected with some reliability by taking into account existing consumption patterns, and using simple norms like per capita consumption and assumption on the increase of population growth for the region. The projection of energy requirements for economic development, however, are a more complex exercise in which the needs and priorities of the rural beneficiaries must be considered, together with the existing and proposed development activities, the creation of economic activities, after taking into account resources endowments and potential as well as various constraints of the region and the other ongoing and proposed rural development programmes. The methodology has to be suitably adapted, depending on the specific situation of the country and its region, as well as the available institutional capabilities.

iv) **Energy Supply Assessment:** The assessment of all available resources, including both traditional and new and renewable energy sources, has to be done over the planning horizon.

v) **Energy Conversion Technologies:** The availability of energy conversion technologies for each resource for matching different end uses has to be assessed for different periods of the planning horizon.

The assessment would include conversion efficiencies, and other appropriate technical characteristics. Only those technologies which are commercially available, or become commercially available during the planning, need to be considered.

vi) **Energy Costs and Prices:** The delivered cost for each energy alternative, which would include the annualized capital cost, assuming the life cycle for each option and interest rate used in the country's planning exercises, plus the annual operating and maintenance cost, as well as the cost of transportation and distribution has to be worked out. The administered prices, as well as the financial ad social costs for each option to (a) the user, (b) the area of region, and (c) the country are also to be worked out, for different phases of the planning horizon.

vii) **Energy Plan:** An integrated rural energy plan is then prepared for the micro-region, on the basis of the above data. The plan should provide the least cost mix of the energy options to meet the different types of energy demand for subsistence and productive activities for the different income groups in the area. Thus the specific targets of the different renewable energy options including solar heating equipment, windpumps, biogas, etc., should be known from the plan.

The framework for integrated area-based rural energy planning described above is only a possible reference and can be suitably modified to suit the specific situation. The plan should provide rational and cost-effective methods for bridging the gap between supply and demand of different energy options, give the optimal mix of energy technologies, on the basis of life cycle costs after taking into account various social, cultural and environmental aspects. Thus the preparation of plans involves matching the energy options social, environmental, economic and technical characteristics to the specific end uses. National policy objectives may be suitably incorporated in the exercise by favouring those options which promote specific policy goals, such as employment generation, improving balance of payment, reducing incremental capital output ratio, etc. The outcome of the energy planning depends on the appropriate choice and role given to the methodological approach, to the final beneficiaries participation, to the institutional aspects and to technological considerations.

FAO has also identified four phases for the establishment of this framework at the micro-level as well as at the macro-level or national and state levels, including the setting up of an institutional mechanism for this purpose (see ref. 7).

The process for setting up the integrated rural energy framework may overcome the constraints and problems by building awareness and local capabilities, for example by providing demonstration and first hand practical experience in the design and implementation of new integrated rural energy planning projects, and by utilizing and developing local expertise.

The task facing the African countries in the development and effective utilization of their local small energy resources in rural areas is tremendous. Each African country must be prepared to create

the necessary political will, adopt relevant policies, legislation, plans and programmes and establish appropriate institutions or strengthen existing ones for that purpose (3). To this end, a clearly defined framework for energy planning, such as this one which has been identified by FAO, is essential in developing a systematic approach to energy planning for the rural areas of African countries.

REFERENCES

(1) - Chinsman, B., "The Diffusion of Small Energy Resources Technologies in Rural Communities", UNFSTD, New York.

(2) - Pasztor, J., "Toward Sustainable Energy Policies", United Nations Environment Programme, Kenya.

(3) - Ndam, S., "Development and Utilization of Energy Resources for Industrialization in Rural Areas in Africa", UNIDO, Vienna.

(4) - Mcnaldi, V., "Some Socio-Economic Aspects of New and Renewable Energy Resources", UNITAR/UNDP Centre on Small Energy Resources, Rome.

(5) - Zereik, G.P., "The Public/Private Industry as Support for the Development of Small Energy Resources Markets in the Developing Countries", CESEN, Genova.

(6) - Best, G., FAO, intervention at the "Experts' Group Meeting on Energy for Rurl Areas of Africa", Rome, March, 1989.

(7) - Chopra, S.K., "Energy Planning for Agricultural and Rural Development", background paper presented at the Experts Consultation on Energy Assessment and Planning for Rural and Agricultural Development, FAO, Rome, April 19-22, 1988.

ENERGY CONSERVATION IN BUILDINGS

Professor V. Korsgaard

Thermal Insulation Laboratory
Technical University of Denmark
Building no. 118 DK-2800 Lyngby

&

S.E. Andreasen, M.Sc.
Head of Dept. of Energy Technology

COWIconsult, Consulting Engineers & Planners
45 Teknikerbyen DK-2830 Virum Denmark
Telephone: +45 2 85 73 11 Telex 37 280 cowi dk

ABSTRACT

This investigation attempts to find building constructions which give the most favorable indoor climate under desert conditions.

Obtaining proper indoor climate is a problem, aggravated by the development of new building materials and the application of modern construction methods. Most developing countries are located in regions with hot climate, where the population normally cannot afford the installation of air conditioning units in their homes.

The new construction materials, which have initially emphasized the importance of indoor climate control, can provide an answer to the problem by proper combination of materials in e.g. sandwich construction. Accordingly, it is theoretically possible to obtain any combination between specific heat and thermal conductivity. By proper selection of materials in addition to using the most suitable shape and orientation of the building the need for air conditioning can be reduced and the size of the required units and energy demand held at a minimum.

1. INTRODUCTION

Many scientists have tackled the problem. They have arrived at a number of sometimes contradictory conclusions depending on the criteria selected. E.g., no general agreement has been reached so far if it is most suitable to orient the building in a NNW-SSE direction in order to distribute the exposure to solar radiation evenly or if the house should be placed in a

north-south direction in order to take full advantage of the fixed shadings and overhangs. The ratio between the length of the house and its width is also of importance.

Studies in Australia indicate the most comfortable temperature to be at 20 to 21°C independent of the relative humidity in the air with an absolute maximum of 30°C before discomfort is experienced. Similar studies in Arabia have shown that the local population prefers a temperature of around 30°C in combination with a wind velocity of 0.8 m/sec.

In the desert the temperature amplitude between day and night is considerable. Solar radiation during the day and the removal of heat during the night are very large. In this climate it is advantageous to have an indoor climate with a very flat temperature curve at the lowest possible level. Heavy and well insulated constructions are required combined with low ventilation.

Natural shading - through trees is of great importance. Frequently, artificial shade is used in the form of reflecting metal surfaces. However, it should be kept in mind that these surfaces at extended exposure to the sun and dust settlements will quickly loose their ability to reflect long wave radiation.

Several methods are available for the evaluation of the performance of various constructions and material combinations. In our work we have used an analog computer.

The calculations have been performed for a bungalow with a floor area of 83.2 m^2, 8 x 10.4 m^2, in desert climate. (See figure 1.)

2. THE BASIC ASSUMPTIONS

(i) Heat transfer coefficients:

$R_{i_{conv.}}$	= 0.28 °C m^2/W	) For the inside
$R_{i_{rad.}}$	= 0.21 "	)
R_i	= 0.04 °C m^2/W	) For the outside
$R_{i_{rad.}}$	= 0.21 "	)

where R is the surface resistance and the suffixes refer the contribution of (rad.) and convection (conv.). U-values for the actual wall and roof constructions are given in table 1 and 2.

(ii) The floor is assumed to be a 10 cm thick layer of concrete with 1 m of earth underneath. Below the layer of earth the temperature is assumed to be constant and equal to the annual mean temperature.

(iii) Ventilation: An exchange of air corresponding to 0.5 hr^{-1} equal 120 m^3/hr has been assumed.

(iv) Shading: The roofs are supplied with fibre cement 10 cm above the roof. The south side is supplied with an overhanging roof line. The The north and south facades have a total of four double glazed win-

dows, 1.2 m^2 each, giving a total window area of 9.6 m^2 or 11.5% of the floor area.

(v) Climatic Conditions: The desert climate is represented by the conditions prevailing at Mosul, Iraq:

Temperature variations during 24 hours:

Summer	21.2 - 43.4°C
Winter	0.0 - 22.2°C

Cloud factor:

Summer	3.23 octas
Winter	2.49 octas

The ground temperature is assumed to be 22.0°C corresponding to the annual mean.

Radiation losses during the night are computed for the following assumptions:

Summer:	$t_{air} - t_{surroundings}$	22°C	for roof
		10°C	for walls
Winter:	$t_{air} - t_{surroundings}$	30°C	for roof
		14°C	for walls

Solar radiation has been computed with a programme designed by the Laboratory for Thermal Insulation at the Technical University of Copenhagen.

(vi) Internal loads:
The calculations are prepared for unoccupied condditions, i.e. internal loads have to be added when determining the total cooling load.

3. RESULTS

The results shown represent the average between the indoor air temperature and the resulting mean radiation temperature, as an approximation to the operative (humanly sensed) temperature.

Only the constructions with optimum performance under summer conditions have been investigated further for their performance during the cold season in order to test the existence of tolerable indoor conditions during the winter months.

Table 1 - Roof Constructions

Type	U-value (W/°C m^2)	Construction (ambient surface first)
R1	2.16	10 mm plaster 200 mm concrete 10 mm plaster
R2	0.33	10 mm plaster 200 mm concrete 100 mm mineral wool 10 mm plaster board
R3	0.39	10 mm plaster 200 mm wood wool cement
R4	0.34	10 mm fibre concrete 100 mm mineral wool 10 mm plaster board
R5	0.75	10 mm plaster 200 mm light weight concrete 10 mm plaster
R6	0.20	10 mm plaster 200 mm light weight concrete 100 mm mineral wool 10 mm plaster board

Table 2 - Wall Constructions

Type	U-value (W/°C m^2)	Construction (ambient surface first)
W1	2.42	10 mm plaster 120 mm concrete 10 mm plaster
W2	0.34	10 mm plaster 120 mm concrete 100 mm mineral wool 10 mm plaster board
W3	1.19	10 mm plaster 100 mm light weight concrete 10 mm plaster
W4	0.30	10 mm plaster 100 mm light weight concrete 100 mm mineral wool 10 mm plaster board
W5	0.75	10 mm plaster 200 mm light weight concrete 10 mm plaster
W6	1.52	10 mm plaster 240 mm brick work 10 mm plaster
W7	0.33	10 mm fibre concrete 100 mm mineral wool 10 mm plaster board

Table 3 - Computed values for roof constructions under summer conditions

(Various roof constructions, wall type W5 and shades on south wall)

	Max. Temp. °C	Min. Temp. °C	Amplitude °C	Mean Temp. °C	Time for Max. Inside Temp.	Phase Displacement hrs.
Outside Air	43.4	21.2	22.2	32.3	14:50	
R1	49.1	33.5	15.6	40.3	19:00	4:10
R2	36.5	30.6	6.0	33.3	19:10	4:20
R3	37.1	32.6	4.5	34.8	19:00	4:10
R4	37.4	29.4	8.0	33.4	10:40	3:50
R5	41.9	31.9	10.0	35.9	19:10	4:20
R6	36.0	30.4	5.6	33.2	19:00	4:10

See diagram 1

Table 4 - Computed values for wall constructions under sommer conditions

(Various wall constructions, roof R6 and shades on south wall)

	Max. Temp. °C	Min. Temp. °C	Amplitude °C	Mean Temp. °C	Time for Max. Inside Temp.	Phase Displacement hrs.
Outside Air	43.4	21.2	22.2	32.3	14:50	
V1	43.5	26.0	16.7	35.1	19:00	4:10
V2	34.0	28.5	5.5	31.3	19:00	4:10
V3	41.6	26.7	14.9	34.1	19:00	4:10
V4	34.1	28.3	5.8	31.2	19:00	4:10
V5	36.0	30.4	5.6	33.2	19:00	4:10
V6	34.9	32.0	2.9	33.5	19:00	4:10
V7	35.1	27.3	8.8	31.7	19:00	4:10

See diagram 2

Table 5 - Computed values for combination of roof type R6 and wall type W4 under summer conditions and changing shading.

	Max. Temp. °C	Min. Temp. °C	Amplitude °C	Mean Temp. °C	Time for Max. Inside Temp.	Phase Displacement hrs.
Outside Air	43.4	21.2	22.2	32.3	14:50	
Shading south	34.1	28.3	5.8	31.2	19:00	4:10
Shading south, roof	34.2	28.8	5.8	31.3	28:50	4:00
Shading south, roof, east, west, north	33.3	27.4	5.9	30.4	18:20	3:30
Shading roof	37.9	29.7	8.2	33.8	19:00	4:10
Without shading	38.2	29.8	8.4	34.0	19:00	4:10

Table 6 - Computed values for combination of roof type R 6 and wall type W 4 under winter conditions

	Max. Temp. °C	Min. Temp. °C	Amplitude °C	Mean Temp. °C	Time for Max. Inside Temp.	Phase Displacement hrs.
Outside Air	22.2	0.0	22.2	11.1	14:00	
R6, W4	23.1	16.2	6.9	19.7	16:30	2:30

See diagram 3.

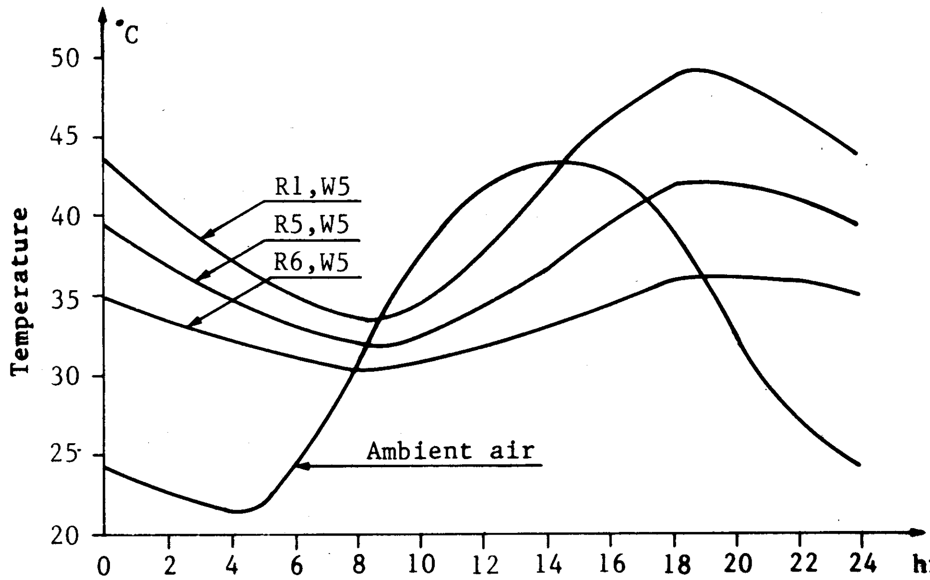


Diagram 1 **Computed indoor temperatures during summer conditions for various roof constructions.**

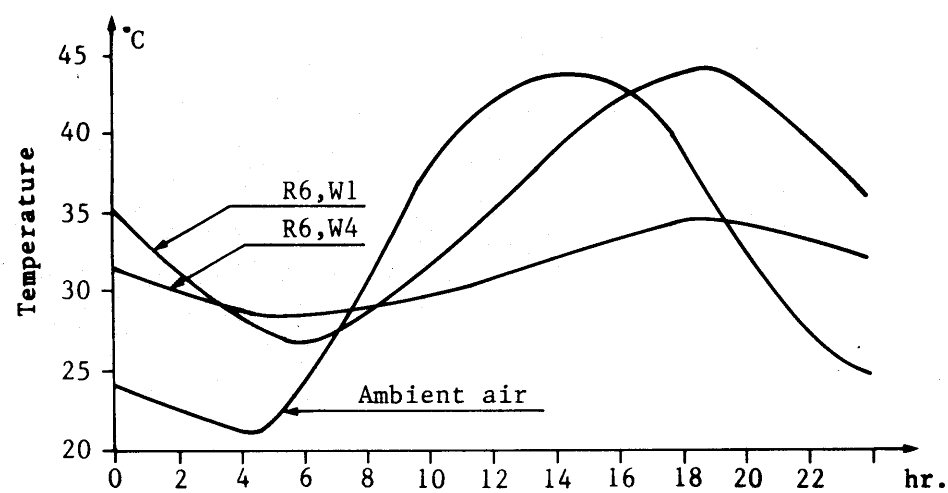


Diagram 2 **Computed indoor temperatures during summer conditions for various wall constructions.**

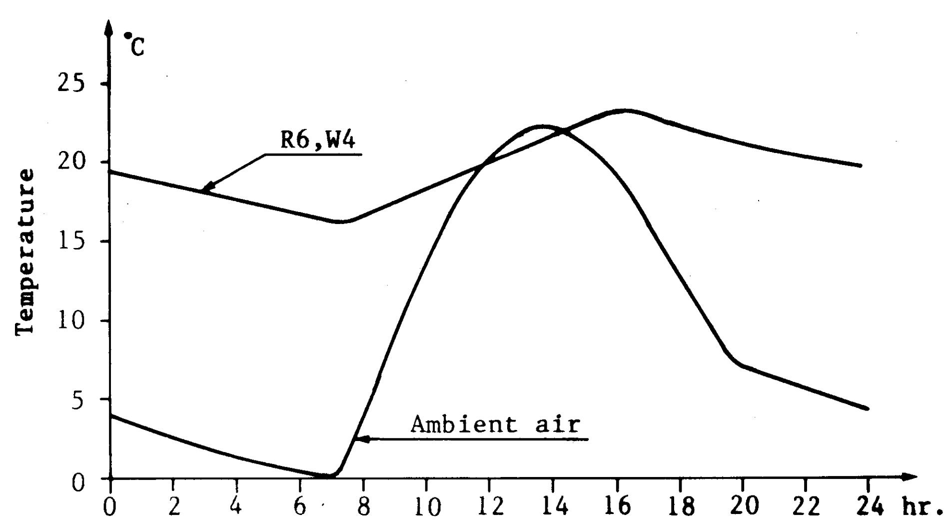


Diagram 3 **Computed indoor temperature during winter for roof type R6 and wall type W4.**

4. CONCLUSIONS

The results for the model under the actual climatic conditions show that the lowest room temperature under summer conditions is obtained by well insulated structures with medium heavy construction towards the outside, i.e. W4, R6. The thermal mass of the floor structure is sufficient to reduce the amplitude of the room temperature, and the thermal mass of the building envelope absorbs and levels the solar gain on the external surfaces.

Shading of external surfaces, e.g. by covered patios, backdrawn facades or ventilated cavity constructions will result in a reduction of the mean room temperature of up to 3.6°C.

The most suitable constructions (W4, R6, shaded) show a mean room temperature of 30.4°C which is 1.9°C below ambient mean temperature. The room temperature varies between 27.4°C and 33.3°C with maximum at 18:20 hours (without taking internal loads into account).

Under winter conditions with ambient mean temperature of 11.1°C the room temperature for the same construction will vary between 16.2°C to 23.2°C without heating. The internal loads from occupants etc. will raise the temperature to comfort level without additional space heating.

From diagram 1 and 2 it is seen that space cooling of the building can be established by night ventilation with ambient air, as the ambient temperature during night is cooler than the room temperature. During day time additional cooling can be established using simple energy efficient evaporative coolers (dessert coolers) instead of the traditional A/C units.

The paper illustrates clearly how the needs for space heating/cooling can be reduced essentially by use of simple structural changes of the building envelope leading to considerable energy conservation for climatizing. Figure 2 and 3 are showing examples of appropriate building designs taking the above into consideration.

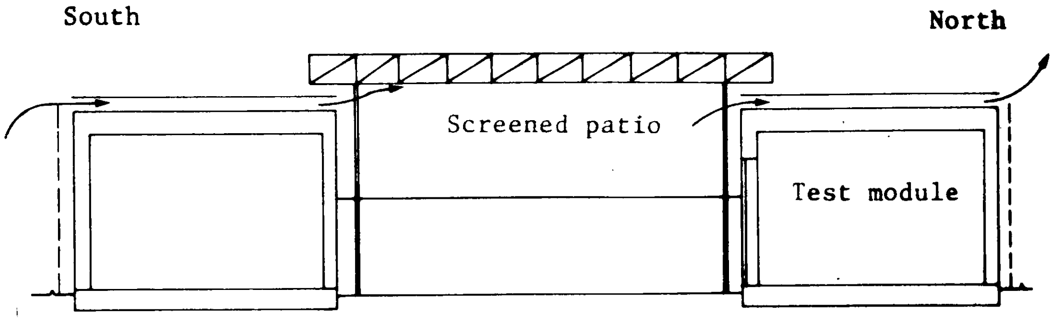


Fig. 1 Sketch of the bungalow used for modelling

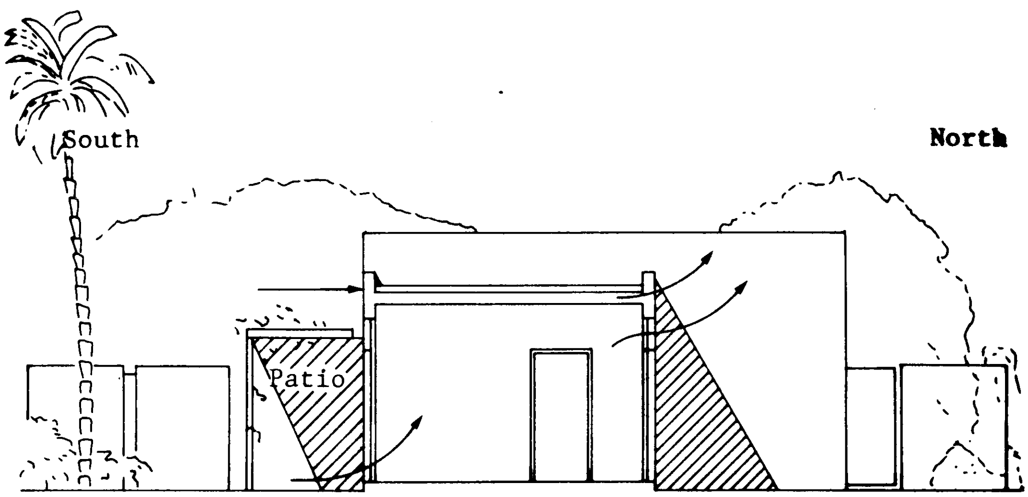


Fig. 2 Example of low energy house designed for Bahrain (Additional cooling is provided using ground water)

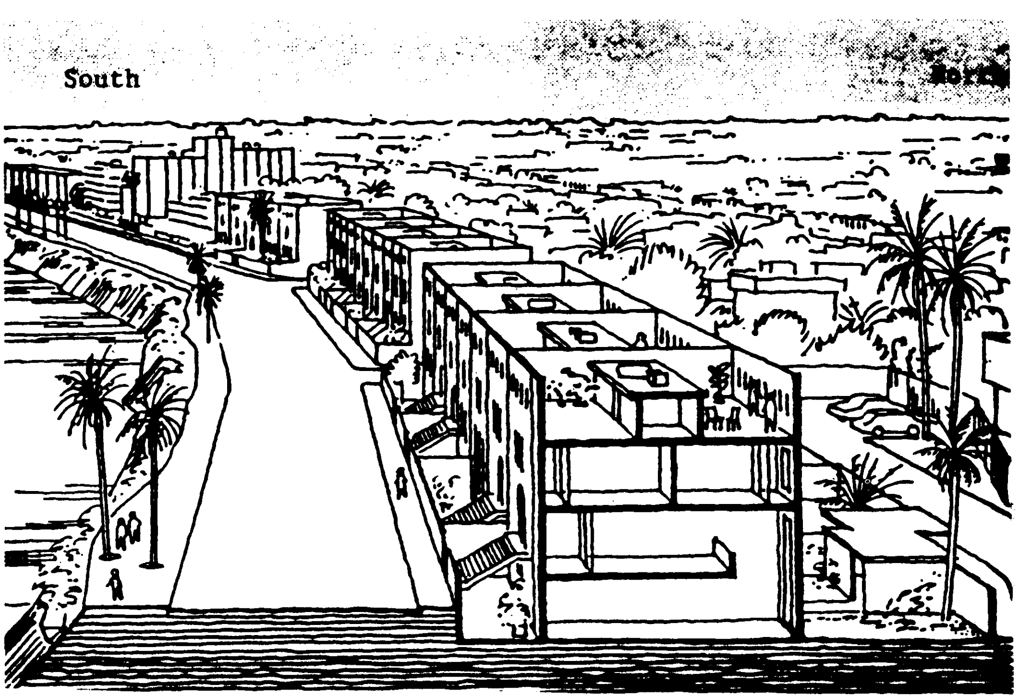


Fig. 3 Example of houses erected in Baghdad using passive cooling by shading of external wall partitions. (Additional cooling is provided using solar powered absorbtion chillers - solar collectors above roof terrace are not shown).

HOUSEHOLD TRANSPORT AND RESIDENTIAL ENERGY USE IN PUERTO RICO

Wallace C. Koehler, Jr., Ph.D.
Center for Energy and Environment Research
University of Puerto Rico

J. Scott McDonald, Ph.D.
Department of Public Affairs
University of Wisconsin-Oshkosh[1]

ABSTRACT

Household energy use patterns in Puerto Rico are placed into the context of the Island's economic, social, geographic, and public policy environments. Puerto Rico having undergone rapid evolution to arrive at its present state, is suggested as a model for other insular nations as they modernize. The paper analyzes household energy consumption patterns based upon a mail survey of randomly sampled households conducted in 1987. Data are analyzed regarding in-house consumption of electricity, gas, LPG, wood, and charcoal; personal vehicle transport; and mass transit. These data are supported via elite interviews and reviews of other surveys. Energy use and policy dynamics are briefly analyzed by comparison with prior household surveys.

Grid electrification, small-scale hydro, wind, solar, wood, ocean wave, and bagasse are each discussed. Public policy, general level of economic development, and other constraints support electrification as the most generally appropriate household energy investment. However, as a public policy investment, electrification may be a socially regressive policy in that the gap between poor and well-off segments of the population is expanded.

Transportation habits to and from work, school, shopping, and recreation are discussed. Here again we see regressive tendencies in that publicly financed mass transit is inadequate while personal auto ownership is beyond the capacity of a quarter of the population.

Policy recommendations regarding electricity, solar water heating, mass transit, and conservation are forwarded.

1. INTRODUCTION

Puerto Rico is not unlike many other developing countries in terms of its geography, and several of its developmental experiences. Puerto Rico is a small, sub-tropical island located in the Caribbean at 18°N, 66°W. Its population is some 3.2 million people, it is approximately 160 km long by 60 km wide. It has a wide coastal plain on its north shore, and has a mountainous interior. There are six distinct climates, ranging from rain forests to deserts. It is therefore a small but complex ecosystem.

Puerto Rico was until 1898 a colony of Spain. Title passed to the United States following the Spanish-American War. Today Puerto Rico is neither a State nor a state. In 1952, the island became, in English, a Commonwealth, or, in Spanish, an Estado Libre Asociado (ELA, Free Associated State)

---

[1]Correspondence to McDonald, Oshkosh, WI 54901 USA. The research was supported by the Center for Energy and Environment Research, University of Puerto Rico. McDonald's travel was supported by Oak Ridge Associated Universities.

with the United States [1]. The semantics matter. Statehood, autonomy, and independence have driven Puerto Rican politics since 1815.

Puerto Rico has undergone a remarkable metamorphosis over the last fifty years. It has moved from a highly agrarian, very poor society to relative affluence and industrialization. Much of this has been rightly attributed to "Operation Bootstrap," initiated in 1947 by Governor Muñoz Marín and endorsed by President Truman. It is a process sometimes described as a mixed blessing [2,3,4,5].[2] Puerto Rico's evolution from an agrarian economy to one based on manufacturing and service sectors has been associated with a shift from rural to urban. Today less than a third of the population is rural. The San Juan metropolitan area is more than four times larger than the island's second city Ponce. San Juan dominates the economic, social, and political life of the island much as a primate city dominates many other developing areas.

Puerto Rican society and economy display interesting mixes between an industrial-market economy and an upper middle-income economy of a developing country.[3] Net income in 1986 was 352% higher than in 1970. Agriculture's share of locally generated net income has decreased to 25% of its 1970 share to the point that by 1986 it accounted for only 1.1% . This compares to the manufacturing, and trade and services shares of 41.1% and 42.0% respectively [6, Table 1364].

The transition which Puerto Rico is going through is documented in the striking changes observable in other socio-economic indicators. The birth rate has declined from 32.5 per 1,000 in 1960 to 19.4 in 1985, a 40% decrease in 25 years. For the same period, infant deaths declined by almost two-thirds to 14.9 per 1,000 live births. The divorce rate has almost doubled to 4.2 per 1,000. During the same interval family income in constant dollars increased 110% to $5,351. Yet much of the island's population suffers from poor living conditions. As of 1980, 11.3% of the population suffered family incomes of less than $1,000 or less than 17% of the median family income. Unemployment rates have remained high, particularly among males, dipping below 19% (1985) for the first time since 1980 [6, Tables 1358, 1359, and 1361].

Puerto Rico's energy situation is also like that to be found in many developing countries. The nation's energy status is a precarious one. The island possesses no fossil fuels. Two per cent of the island's electricity is generated from hydropower, the balance from imported oil. Very tentative explorations for offshore oil have been initiated. In consequence, Puerto Rico, like many other small island systems, is particularly sensitive to the vagaries of world oil prices. Alternative energy options have been explored at some length [8,9] and are expected to play a major role in Puerto Rico's energy strategy [10].

2. ENERGY POLICY DEVELOPMENT

2.1. Technology Research and Choice

The cornerstone of Puerto Rico's energy development, like that in many developing areas, has been electrification. Therefore, a brief review of its experiences with electrification is in order. Electrification has been a necessary but not sufficient engine driving Puerto Rico's development [11,12] and is a necessary precondition to industrialization [13,14,15,16]. It may be, however, something of a mixed blessing [17,18].

It is suggested here that electrification in Puerto Rico has been a positive process; that over a period of less than twenty years (early 1950s-1965) rural (and to a degree, urban) Puerto Rico changed from an almost non-electric to an almost totally electrified society. The reasons for this were 1) a strong commitment from the Commonwealth and federal governments in political as well as financial terms, and 2) a meaningful system of subsidies, which continue, for rural and/or poor consumers.

---

[2]According to the Economic Development Administration (Fomento), in 1982 there were 1030 manufacturing firms on the Island (in two-digit Standard Industrial Classifications 20 to 39. Fomento reports more than 1580 in January 1988. The single largest group is the pharmaceutical industry (SI C 2834): 110 plants representing 78 companies which produce drugs and preparations.

[3]See World Bank [7] for definitions. The middle-income category includes 23 countries such as Hong Kong, Singapore and Greece as well as less well-off countries. Several members of this group are NICs (newly industrialized countries).

Puerto Rico's first significant rural electrification project was the construction of a hydroelectric dam by the Servico de Riego de la Costa Sur (South Coast Irrigation Service). Electric service was provided to cities by three private utilities located in San Juan, Ponce, and Mayagüez. In 1927, an agency of the Insular Government, Utilización de las Fuentes Fluviales (Use of Water Power) was created to explore the development of hydro resources for the island. During the Great Depression of the 1930s, both the US Public Works Administration and the Puerto Rico Reconstruction Administration provided not insignificant funds to build dams and construct power lines.

Further and more extensive development of the power system was inhibited however, by the lack of autonomy of the government agency. It was not empowered to issue debt, and had to rely on government operating funds for construction. In 1941 the Puerto Rico Water Power Authority (renamed Puerto Rico Electric Power Authority in 1979) was created to provide an island-wide utility with the competence to issue "triple" tax exempt bonds. The Authority was established as a public corporation, which it remains today. It was charged, under its General Program to improve and expand both urban and rural electrification. Rural electrification, in turn, was given special emphasis under the Rural Electrification Program beginning in 1951. In 1941, only 12% of rural households were electrified. By 1965, nearly all were [19]. It is estimated that today 99.5% of all households in Puerto Rico are serviced by the Puerto Rico Electric Power Authority (PREPA). [4]

Until the first oil price shock in 1973, the residential price of electricity had not changed since the inception of PREPA. The base price was set at $0.02025/kwh. Because of Puerto Rico's sensitivity to world oil prices, PREPA was forced to raise its base prices in 1973 and again in 1979. Puerto Rico was once a low electric price haven, today its prices are only competitive by mainland standards [20]. Prices have declined. In the mid 1980s because of declining oil prices, consumers paid $0.1059 in 1985 to $0.078 in 1987.[5] The increase in the cost of oil and consequently for electricity had a deleterious impact on the Puerto Rican economy in the 1970s and early 1980s [21,22,23].

Today, Puerto Rico's electricity generation capacity is significantly over built. Most recently PREPA reported a 1,900 mw(e) peak demand against a 4,200 mw(e) nameplate capacity [24]. Plans are to export a portion of this excess capacity to the Dominican Republic via a proposed undersea cable. With considerable investment in the present over built generating capacity, new capacity must be extremely attractive to receive any consideration. With capital costs for the present system already sunk, new generating capacity must have total capital and operations and maintenance [O&M] costs below the O&M costs of the existing facilities. Despite these rigorous criteria, investigation into alternative generation technologies has proceeded.

Small-scale hydro has received some attention but hydro is not a viable alternative beyond the present two percent of generation capacity it presently occupies. Indeed nearly all economically viable hydro sites have been exploited. Other alternative generation schemes have been investigated including solar, wind, ocean wave, OTEC, biogas, and bagasse. Each presents benefits in that they would decrease dependence on foreign supplies of fuels, but each exhibits weaknesses.

Bagasse, the cane residue from sugar production, has been suggested as a natural for Puerto Rico [26]. But, with oil and sugar prices depressed for the foreseeable future, it may not be a near term option, in economic terms.

---

[4] To finance this expansion, PREPA received direct grants from the ELA government. It has also used debt instruments. In 1952, the REA loaned PREPA $6.4 million over 35 years at 2 per cent interest for further expansion of the rural electric system, and addition sums were lent or bonds purchased by the REA in subsequent years. By September 1987, PREPA had issued to the REA a total of $238.7 million, of which $173.8 million were outstanding at 2 and 5 per cent. PREPA plans further REA borrowing over the next five years of $147.1 million, also at 5% [24]. Puerto Rico has a comparative advantage over other developing areas in that it has had access to significant capital and capital markets, over a protracted period of time, at favorable rates and tax treatment to develop its electric infrastructure.

[5] It should be noted that the average residential consumer in Puerto Rico consumes less than half the electricity as does his/her mainland counterpart [in 1986, 3840 kwh versus 9068 kwh], but it should also be noted that 14.5% of US households space heat with electricity, [25] while there are no space heating needs in Puerto Rico.

The commercial viability of biogassification has been investigated. It has been determined that in those cases where livestock herds were sufficiently large biogassification would be an economically marginal investment if O&M were performed in a timely fashion. Timely performance of O&M is an environmental weakness which may be difficult to overcome [27].

OTEC has been investigated with specific application to electricity generation in Puerto Rico. In the long run OTEC may be well suited to tropical applications, however in the near and short terms technical obstacles limit its viability. Wind generation is presently under review and it is too early to pass judgment on its viability. Fast growing tree species have been investigated as an energy source in Puerto Rico. But since almost all households cook on LPG, gas, or electric stoves it is unlikely that wood will ever again become a significant source of household energy for the island.

Energy planners and scholars in Puerto Rico realize that the island will eventually want to decouple from the carbon based energy economy to which it is so closely tied. In the near and medium term, as we have just discussed, the alternative sources of energy for the generation of electricity are not viable. Of course two technologies have yet to be discussed--nuclear and photovoltaics. Nuclear received serious investigation until the late 1970s but the idea was rejected. Several factors contribute to nuclear being an inappropriate technology for Puerto Rico and many other insular nations. First, the unit size of the present generation of nuclear power plants is too vast for this group of nations. Additionally, Puerto Rico is geologically active increasing the stakes of nuclear development.

Photovoltaics are falling in price and may, in the long run, be viable in helping Puerto Rico out of the carbon economy. However, prices will have to decline a good deal more and local O&M issues will have to be overcome [28]. Timely O&M is not a forte in Puerto Rico, and they are essential to the operation of a photovoltaic generation plant. This will particularly be the case in Puerto Rico because the island lies in the Saharan dust belt.

2.2 Subsidies

PREPA presently subsidizes residential consumers who consume 425 kwh/month or less. These customers are billed a base rate plus a fuel cost inflator (as are all customers) less a percent negotiated periodically between PREPA and the ELA government. According to PREPA, 76% of residential customers received the subsidy at some time during 1987. This transfer payment from government constituted some 16% of revenues from the residential sector [24 p.24].

A second set of subsidies for energy devices and appliances in Puerto Rico are for solar hot water heaters. The tax law provides a deduction for solar hot water heaters. In addition the Puerto Rico Office of Energy is exploring means to assist the local solar industry.

3. HOUSEHOLD ENERGY CONSUMPTION

This section reports the findings of the 1987 CEER Survey supplemented with prior energy surveys and U.S. Census data. The data reported herein are representative of the universe of all households on the island. The 1987 survey data were gathered via a mailed questionnaire sent to a random sample of all households on the mailing list of the island's electricity utility. Since fully 99.5 percent of households have electricity supplied by the grid, we are confident that with minor weighting adjustments, the findings are generalizable to the entire island. The data are based on 235 responses to a single mailing to 1,200 households (approximately 20 percent).[6] The 18 page instrument employed mostly closed-ended questions to gather detailed data on household profiles (incomes, size, dwelling and possession characteristics), energy consumption (electricity, gas, and other fuels), transportation habits (automobile usage, car pooling, and public transport), and conservation practices.[7] The following analysis presents the household data for all respondents, and as well as disaggregated by income groups.

---

[6]Follow-up mailings were not undertaken due to difficulties with the mailing list. The n of 235 is small considering that the 1980 Census reports 871,365 households.

[7]All data were analyzed employing SPSS-PC. Data were carefully verified, and data error approaches zero percent.

3.1 Household Profile

Households are profiled by dwelling construction and size indicators, number of members, and selected socioeconomic variables. The representativeness of the sample is displayed via comparisons with U.S. Census data and previous surveys on several indicators.

The 1980 Census of Housing reports data on household size, plumbing, structural characteristics, and household incomes for the entire Commonwealth and various localities. The CEER survey collected parallel indicators.

Table 1 displays measures of central tendency for Census and sample on several indicators. In terms of household size and percent of units owner occupied, two fairly stable indicators, the sample and Census medians are nearly identical.

TABLE 1
Household Indicators:
U.S. Census and CEER Sample Compared*

Year Enumerated	CENSUS 1979	SAMPLE 1987
Number of Rooms	4.9	5.8
Persons	3.46	3.39
Single Units (%)	85.1	79.1
Multiple Units (%)	14.9	20.9
Complete Plumbing (%)	86.6	99.1
Owner Occupied (%)	68.5	69.3
Income ($)(median)	7,738.	10,680.
Below poverty line (%)	62.4	48.8

* Means unless otherwise indicated.

Source: [33] [34]

The CEER sample median income is 38 percent more than that reported for 1979. The data reflect the increased standard of living experienced both in Puerto Rico and the United States during the 1980s.[8] Between 1979 and 1985, median income for U.S. households (not families) increased 43.5 percent [29]. As is shown in Table 1, the number of households below the defined poverty threshold fell from more than 60 percent to less than 50 percent over the period.

Comparing the CEER survey data to data from the 1980 Census we find larger housing units (5.8 room versus 4.8 for the Census). Almost all the sampled households in 1987 (99.1%) have complete plumbing versus 86.6 percent for the Census in 1979. This differential is in part a reflection of the public health advances made by the Puerto Rican government over the last several years.

In addition, there have been several surveys of electricity use in Puerto Rico, the first conducted by PREPA [30] in 1980 and the second by CEER [21] in 1982. Comparisons between these years and the 1987 survey are shown in Table 2. There have been some remarkable gains in appliance ownership over the seven year period: the number of color televisions has virtually doubled, the number of solar water heaters has risen more than five-fold.

Electricity consumption, in general, has likewise increased, as is shown in Table 3. For example, in 1980 26.8% of households consumed less than 150 kwh per month. That number had fallen to 7.9% in 1987. The percent of households increases in 1987 as consumption levels increase in virtually all other strata.

3.2 Quality of Life and Electricity Consumption

This section discusses the sample in terms of multiple indicators of quality of life including housing unit characteristics, energy consuming household devices, and vehicles. The data are

[8]The Census data are for families, units of two or more related individuals, while the CEER data are reported for households, any number of related and unrelated individuals residing in the same housing unit. Therefore comparison should be approached with considerable caution.

TABLE 2
Comparison of Household Ownership of Appliances
1980, 1982, 1987 In Percent

Device	1980	1982	1987(a)	1987(b)
Color TV	42.3	30.9	81.2	80.7
Black and White TV	57.7	33.9	44.7	44.2
Stereo	69.7		68.1	
Portable Fan	55.4		77.9	
Air Conditioner	27.4	13.5	19.5	13.7
Electric Stove	35.7	44.8	42.1	39.4
Iron	82.3		93.6	
Non-Solar Water Heater	42.8	31.7	48.7	46.7
Shower Heater	19.1	23.0	19.4	20.3
Clothes Washer	82.6	77.8	86.7	85.5
Dryer	7.2	4.0	13.6	9.2
Frost Free Refrigerator	64.8	58.9	83.0	80.9
"Frost" Refrigerator	32.2	38.7	17.3	18.8
Toaster	37.5		57.4	
Dishwasher	1.8	1.2	5.3	2.7
Solar Hot Water Heater	2.8	2.0	14.7	16.5

Sources: 1980 [30], 1982 [21].

Note: The 1982 survey is biased toward low income households. For reasons not explained, households with incomes over $30,000 were excluded. Column 1987(a) reports actual findings. Column 1987(b) is an attempt to match the 1982 and 1987 surveys. Income was corrected to 1982 dollars with the CPI. Households with incomes greater than $30,000 (1982) were dropped. Data from the remaining 1987 cases are reported in column 1987(b).

TABLE 3
Electricity Consumption in Puerto Rico
Strata by Percent of Households

KWH/MONTH	1980	1987
0-150	26.8	7.9
151-300	29.6	28.7
301-550	28.6	41.9
551-1000	10.0	12.3
1001-2100	4.4	7.9
2100 or more	0.9	1.1

1980 Source: [30]. Strata are those employed by PREPA in its reports.

disaggregated into groups based on their relationship to the poverty line.[9] Herein and elsewhere in this report, three income groups are employed: 1) low income or poor, at or below the poverty line, 2) middle income, above the poverty line and less than or equal to four times the poverty line, and 3) high income, more than four times the poverty line. Analysis of variance, F-test, or chi-square are employed to determine the statistical significance of intergroup variations on each indicator.

[9]Poverty statistic calculated using the criteria defined by US Department of Energy [25, Table C2, p. 290]. Households are defined to be at the poverty line according to family size and income. These levels are: one person, $5,000; two persons, $7,500; three persons, $9,000; four persons, $11,000; five persons, $12,500; six persons, $14,000; seven persons, $15,000; eight persons, $17,500; and nine persons or more, $20,000.

TABLE 4
Profile of Energy Consuming Devices
and Other Indicators

Device	Percent Who Possess	Mean Total	US Poverty Levels: Low	Medium	High
Color TV	72	1.07	0.81	1.27	1.63**
B&W TV	45	0.49	0.51	0.48	0.45
Stereo	68	0.75	0.59	0.85	1.20**
Radio	75	1.25	1.01	1.50	1.80**
Ceiling Fan	33	0.63	0.38	0.77	1.66**
Portable Fan	88	1.41	1.24	1.14	1.30
Air Conditioner	19	0.35	0.09	0.41	1.52**
Stove with Oven	42	0.42	0.33	0.51	0.75**
Stove without Oven	8	0.08	0.05	0.12	0.06
Iron	94	0.98	0.98	0.97	1.17*
Hair Dryer	36	0.42	0.27	0.53	1.11**
Non-Solar Water Heater	51	0.52	0.30	0.71	0.78**
Showerhead Heater	19	0.20	0.31	0.10	0.19*
Electric Water Pumps	2	0.02	0.0	0.02	0.13**
Clothes Washer	87	0.87	0.80	0.92	1.00*
Dryer	14	0.14	0.03	0.18	0.60**
Frost Free Refrigerator	83	0.86	0.74	0.96	0.87**
"Frost" Refrigerator	17	0.18	0.26	0.10	0.25*
Juicer	7	0.07	0.04	0.09	0.06
Microwave Oven	28	0.28	0.08	0.45	0.69**
Vacuum Cleaner	32	0.32	0.10	0.44	0.93**
Toaster	57	0.58	0.47	0.69	0.81**
Hotplate	8	0.13	0.13	0.14	0.20
Blender	74	0.75	0.56	0.91	0.94**
Dishwasher	5	0.05	0.0	0.06	0.34**
Garbage Disposal	8	0.08	0.0	0.13	0.38**
Sewing Machine	43	0.49	0.48	0.59	0.55
Rooms in House	100	5.75	5.32	6.01	6.81**
Toilets	99	1.47	1.17	1.69	2.18**
Years in House	N/A	14.66	16.12	13.00	13.11
Age of House	N/A	19.76	21.68	17.62	15.64
Persons in Household	N/A	3.33	3.46	3.25	2.88
Lightbulbs in House	100	10.72	8.24	11.97	18.18**
Lightbulbs Outside	83	2.89	2.17	3.45	4.49**
Cars and Stationwagons	74	1.08	0.74	1.38	1.49**
Vans/Pickups/Jeeps	14	0.15	0.05	0.25	0.13**

* F statistic significant at less than or equal to 0.05; ** 0.01

Not surprisingly, there exist statistically significant relationships between income group and many of the quality of life indicators. Number of rooms, number of toilets, and possession of cable TV is positively associated with income. Type of housing (public housing, apartment, single family) is also associated with income. However, there is no statistically significant relationship between construction materials (wood or concrete), running water, age of structure, and possession of a satellite dish.[10] Additionally, household size is not related to income level.

[10]Almost all housing units are constructed of masonry due to insect and hurricane threats. Mortgage lenders require masonry construction.

The relationship between the number of vehicles and income is statistically significant. As will be discussed in the Energy Expenditure section below, lower income households are much less likely to possess a vehicle.

For energy consuming household devices, we find that most, 22 of 28, have an association with income. Comparing the data in Table 2 with that found in Table 4 we find that of the six items not statistically related to income, two are the lower cost alternatives to more expensive devices, portable fan as opposed to ceiling fan and black and white TV as opposed to color TV, three are fairly rare regardless of income, stove without oven, blender, and hot plate, and one, sewing machine is more likely to be found in better-off households, but not to a statistically significant degree. The data in the two tables plainly indicate that better-off households possess many more electrical devices. This is particularly evident for high income households.

TABLE 5
Housing Characteristics
Puerto Rico 1987

Characteristic	Total Sample	Poverty Level Low	Medium	High
		Average (Mean)		
Persons in household	3.33	3.46	3.25	2.88
Rooms in house	5.75	5.32	6.01	6.81***
Toilets	1.47	1.71	1.69	2.18***
Age of house-years	19.76	21.68	17.62	15.64
Years in house	14.66	16.12	13.00	13.11
House constructed of (in Percent):		Column Percent		
Wood	5.2	8.2	3.8	0.0
Concrete	84.0	76.4	89.9	92.3
Both	10.7	15.5	6.3	7.7
House has:		Percent of Subgroup		
Running water	98.8	98.5	100	100
Satellite TV	1.4	1.1	0	0
Cable TV	28.1	19.0	25.8	89.0[1]
Ownership status of housing:		Column Percent		
Own	72.4	59.9	83.7	85.3
Rent	10.2	11.1	8.4	14.7
Subsidized	9.0	13.1	5.9	
Public housing	7.5	14.4	1.3	
Agregado[2]	.9	1.5	.7	
x^2=20.3 p=.0093				
Type of housing				
House	79.1	79.1	83.1	71.4
Apartment	20.9	20.9	16.9	28.6

[1]Cable TV chi-sq significant at .0002

[2]"Squatter"

3.3 Energy Expenditures

This section reviews household energy expenditures by energy source and by household income. The survey instrument gathered data on household expenditures including: gasoline for automobile travel, electricity, natural gas (pipe gas), bottle gas (LPG), charcoal, kerosene, and fuel wood. Cost data are employed herein because they are more reliable than raw quantity data. By employing dollar amounts it was possible to achieve a degree of consistency not possible when quantities were reported in such varied measures as sacks and pounds (in the case of charcoal), cords and feet (fuel wood), and bottles and pounds (LPG). Additionally, dollar amounts are more readily recalled by consumers than are quantities in seemingly abstract fuel/energy measures such as kilowatts, liters, pounds, and therms.

The reliability of energy cost data varies. Electricity data are the most reliable because respondents were asked to refer to their past electricity bills which are usually kept as payment records. Data are not so readily accessible for other sources of energy; one must rely on respondents' recollections. Table 6 displays data on average household energy expenditures for all households and for households grouped by income.

TABLE 6
Annual Household Energy Expenditures

		Household Income Group*		
	Entire Sample	Low	Mid	High
Household Income (Mean)	$16375.17	$4768.63	$20361.38	$59465.89
Household Size (Persons)	3.4	3.6	3.3	2.9
Total Energy Expenditures	$1218.13	$874.95	$1479.14	$2258.89
--as % of Income**	14.6	21.3	8.0	5.0
Electricity Expenditures	$392.26	$305.23	$375.24	$1136.18
--as % of Income	4.9	8.0	2.0	1.8
Gasoline Expenditures	$758.28	$417.91	$1121.71	$1213.33
--as % of Income	8.2	10.2	6.6	2.4
Other Energy***	$62.40	$84.67	$40.60	$26.42
--as % of Income	1.5	2.9	0.3	0.1

* Low--Less than or equal to the U.S. poverty level.
Mid--More than poverty level and less than or equal to four times poverty level.
High--More than four times the U.S. poverty level.

Poverty statistic calculated using the criteria defined by Table C2, p. 290. See footnote 9 for definition of poverty thresholds.

** Computed on basis of individual household level data. Vari from group mean due to skewed distribution.

*** Includes kerosene, charcoal, LPG, natural gas (available in San Juan only), and wood.

The mean total annual energy expenditure was $1,218.13 or 14.6% of total household income. The mean household income was $16,375.17. Households in Puerto Rico proportionally expend approximately twice as much on energy as the U.S. urban consumers who spend an average of 7.36%

of their expenditures on energy. Disaggregating total energy expenditures into three major categories: electricity, gasoline, and other, we find that P.R. households expend 4.9% ($392.26), 8.2% ($758.28), and 1.5% ($62.40) of incomes respectively. While U.S. data were not available for precisely parallel categories there is sufficient commonality to conclude that P.R. households are spending greater proportions of their household incomes on these energies than their mainland counterparts. CPI energy data are categorized into three groups. For piped gas and electricity, fuel oil and other household fuel commodities, and motor fuel as percent of all expenditures are 4.458%, 0.395%, and 2.903% respectively [31, Table 1].[11] The most striking differential between Puerto Rico and the United States is the proportion of income expended on gasoline which averaged 8.2 percent and 2.903 percent respectively.

Comparing energy expenditures across income groups, not surprisingly, low income households are expending much greater proportions of their incomes on energy than are middle and high income households. Households below the poverty level (low income) were expending 21.3% of their incomes on energy as compared to only 5% for the high income (incomes greater than four times the poverty level). Poor households in Puerto Rico expend almost three times the U.S. average percent on energy [25,32].

The largest energy expenditure differential is between low and high income household expenditures for electricity. Low income households spend approximately one-fourth as much on electricity as do high income households, yet spend proportionally more than four times as large a share of their incomes.

High income households expend almost three times more for gasoline than do low income households. Yet, as a percentage of income, high income households again are spending less than one-quarter as large a share of their incomes as must low income households (2.4% v. 10.2%).

TABLE 7
Household Energy Expenditures: Other Category

		Household Income Group*		
	Entire Sample	Low	Mid	High
Total Other Energy**	$62.40	$84.67	$40.60	$26.4
--as % of Income	1.5	2.9	0.3	0.1
Percent of Other Energy Expenditures:				
--LPG	93.8%	97.1%	96.7%	67.5
--Natural Gas	3.8%	1.7%	--	27.8
--Charcoal	1.3%	0.7%	3.0%	4.7
--Fuel Wood	0.1%	0.1%	--	--
--Kerosene	0.3%	0.3%	0.3%	--

* Low--Less than or equal to the U.S. poverty level.
Mid--More than poverty level and less than or equal to four times poverty level.
High--More than four times the U.S. poverty level.

** Household energy expenditures less electricity and gasoline

-- Less than 0.1%.

[11] CPI data are proportion of expenditures which generally is less than the CEER indicator total income. CPI data are for all urban consumers averaged by U.S. city while CEER data are island wide inclusive of rural households.

Low income households have the lowest dollar expenditures for electricity and gasoline. For expenditures for other energy, including kerosene, charcoal, LPG, natural gas, and wood, low income households have the highest expenditures. This is a function of the cooking fuels used within these households. For both low and medium income households more than 90% of other energy expenditures are for LPG, which, except for a small amount of water heating and a very small amount of space heating is exclusively a cooking fuel in Puerto Rico. Less than 70% of high income households' other energy expenditures are for LPG. This group of households spend on average almost 28% of other energy expenditures on natural gas, which is available only in Old San Juan. Middle income households spend less than one-third as much on other energy as do poor households. Middle income households are more likely to use electricity or natural gas for cooking than are poor households.

4. TRANSPORTATION

The automobile dominates household transportation in Puerto Rico. Three-quarters of households possess at least one motor vehicle ("first vehicle": auto 91%, pickup 3%, jeep 3%, or van 2%). Of Puerto Rican households, 25% have no vehicle, 49% have one, 19.4% have two, 4.6% have three, and 1.5 percent have four or more. High and middle income households are more likely to own a motor vehicle than are their less well-off counterparts, but not to such a degree as one would expect. Table 8 clearly indicates that the extremely poor households in both rural and urban areas tend to be the ones without a vehicle. Insufficient public, particularly mass transit, as will be discussed below, necessitates that each household have an automobile.

TABLE 8
Income by Possession of Motor Vehicle and Place of Residence
Possession of Motor Vehicle

Location	All	Yes	No
Cases			
Urban	$19,761	$23,376	$4,941
Rural	$13,243	$15,956	$3,625

Journeys to work account for 45 percent of all weekly milage. Recreation, the second most intensive vehicle usage accounts for slightly less than one quarter, with other, shopping, and school accounting for 13, 11, and 9 percent respectively. Poor households, as Table 9 displays, average more weekly miles than their middle income counterparts. In only one category, journey to work, do middle income households put more milage on than do low income households. The explanation for this is found in Table 10 where we find that only 40 percent of low income households drive to work versus 93 percent of middle income households. The percentages and milage for the other four types of journeys are similar. This is readily explained by the high unemployment rate in Puerto Rico and the weak rural public transportation system.

TABLE 9
Miles per Week by Type of Journey
(N)

		Income Group		
	All	Low	Middle	High*
All journeys	231 (109)	258 (34)	201 (61)	293 (14)
Work	104 (91)	85 (30)	110 (49)	125 (12)
School	21 (91)	22 (30)	17 (49)	35 (12)
Shopping	26 (91)	27 (30)	24 (49)	34 (12)
Recreation	54 (92)	68 (30)	39 (50)	87 (12)
Other	29 (91)	41 (30)	16 (49)	4 (12)

* Low--Less than or equal to the U.S. poverty level.
Mid--More than poverty level and less than or equal to four times poverty level.
High--More than four times the U.S. poverty level.

TABLE 10
Percent of Households with Vehicles
by Type of Journey and Income Group
(N)

Type of Journey	All	Low	Mid	High*
Work	72 (63)	40 (12)	93 (42)	75 (9)
School	38 (33)	48 (15)	31 (14)	34 (4)
Shopping	82 (72)	81 (25)	84 (38)	80 (10)
Recreation	75 (66)	75 (23)	71 (32)	92 (11)
Other	31 (28)	36 (11)	33 (14)	17 (2)

* Low--Less than or equal to the U.S. poverty level.
  Mid--More than poverty level and less than or equal to four times poverty level.
  High--More than four times the U.S. poverty level.

NOTE: Chi-square for work significant at .001. All other chi- square not significant at .05.

Usage of public transportation is low in Puerto Rico. Table 11 displays mean weekly usage of the three modes of public transport existent in Puerto Rico. The guaguas[12], or buses, are publicly operated and almost exclusively serve the island's larger urban centers. Fares for guaguas are subsidized by government and are set at 25 cents per trip, including transfers. Publicos are privately operated conveyances, most typically vans but sometimes cars. They operate throughout the island, following more or less fixed routes and schedules, providing the only public transportation to many rural areas.

TABLE 11
Public Transport Usage by Urban-Rural by Possession of Vehicle*
Total Weekly Trips

Type of Transport	All Households	Urban			Rural		
		All	Yes	No	All	Yes	No*
All Public Transport	2.3	2.5	1.5	7.8	2.0	1.9	2.6
--Publico	1.4	1.3	.9	3.8	1.6	1.5	2.1
--Guagua	.8	1.1	.6	3.4	.4	.4	.4
--Taxi	.1	.1	0.0	.6	0.0	0.0	.1

* Possession of vehicle: automobile, van, pickup, jeep, motorcycle.

Urban households average slightly more trips per week via public transportation than do rural households (2.5 v. 2.0). Not surprisingly, urban households without vehicles average five times more public transport usage than households with vehicles. This differential is not evident in rural areas where households without a vehicle average less than one more trip per week than those with a vehicle. Journeys to and from school account for 41% of publico usage followed by shopping, work, and recreation at 24, 22, and 14% respectively. Journeys to school and to work account for 41% and 39% guagua trips.

The lack of sufficient public transportation for all households, and particularly for the low income households could be offset by car pooling and fuel efficient vehicles. If one accepts the common notion that newer vehicles are more fuel efficient than older ones, low income households are, not unexpectedly, at a disadvantage with their significantly older vehicles: low income--8.70 years, middle--4.88 years, and high--2.88 years (F significant at .001).

[12]The term "guagua" requires explanation. It is "bus" in Puerto Rican Spanish, but means other things elsewhere, for example "baby" throughout much of Latin America. There are numerous other examples which range from the amusing to the vulgar.

TABLE 12
Journey to Work: Private Vehicle Occupancy

	All		Urban		Rural	
	1980	1987	1980	1987	1980	1987
Drive Alone	82.2	81.7(94)	83.0	79.7(47)	79.7	79.2(42)
2 Person Car Pool	12.2	16.8(19)	12.1	20.3(12)	12.2	15.1(8)
3 Person Car Pool	2.7	.5(1)	2.4	0.0(0)	3.6	1.9(1)
4 Person Car Pool	1.4	.5(1)	1.3	0.0(0)	1.9	1.9(1)
5 or More Persons	1.5	.5(1)	1.2	0.0(0)	2.5	1.9(1)
Persons per Private Vehicle	1.11	1.45(121)	1.11	1.20(59)	1.14	1.36(53)

1980 data from [33]. Table 47. 1980 data for workers 16 years and older using private vehicles. 1987 data from CEER Household Survey discussed in the text. 1987 data include all occupants (which may or may not be a formal car pool) occupying the vehicle on the journey to work.

There is little car pooling in Puerto Rico. The survey found that average vehicle occupancy for the trip to work was 1.45 persons. Four out of five autos have a single occupant for the journey to work. While the survey n was relatively small (121), these data were corroborated by Census data. In fact, the survey data indicate that occupancy has increased from the 1980 census figure of 1.11 to 1.45 [33, Table 47].[13]

5. HOUSEHOLD EENERGY CONSERVATION

In addition to measures on vehicle conservation, the survey instrument gathered considerable data on in-house conservation measures. Table 13 presents data on the percentage of households adoption of each of 15 conservation measures. The data in the table are largely self-explanatory and indicate widespread conservation practices. Adoption is stable across income groups [as indicated by chi-square statistics] on 12 of 15 measures. For three measures, there is a statistically significant difference in adoption rates between income groups. For two conservation measures, use dryer less and reduce air conditioner use the explanation can be found in Table 5; low income households simply possess these devises at much lower frequencies. The third difference is that better off households tend to be less likely to shift to lower wattage bulbs.

Table 14 indicates that there is only one significant difference in the adoption of conservation measures between owner occupied and rental units. This is explicable through the fact that fully 72.4% of the households surveyed were owner occupied. The single significant difference, the application of roof insulation, is the most expensive measure. Additionally, renters are more likely to live in multistory buildings where roof insulation would not be an important conservation to most occupants. In contrast the application of reflective paint is constant between owner occupied and rental units. Two factors explain this: reflective paint is much less expensive than insulation and reflective paint is widely used to help seal the concrete roofs which cover almost all units.

The incidence of solar water heaters, as noted above, has increased five-fold since 1980. The ELA government provides tax credits for installation of solar water heaters. There is some popular distrust with this technology. This distrust is the result of wide spread equipment failures due to inexperienced or shady sales and installation personnel. At present the ELA Office of Energy is drafting regulations to correct this problem.

6. CONCLUSIONS AND POLICY IMPLICATIONS

The data provide useful insights into understanding many of the dynamics of household energy usage in Puerto Rico. To the extent that the Puerto Rican case is similar to other developing areas, it may be generalizable. Factors supporting the development of generalizations are Puerto Rico's geography, dependence on foreign oil, and to a degree its colonial experiences. However, Puerto

[13]Census data for workers 16 years and older; CEER data include all occupants.

TABLE 13
Conservation Measures by Income Group

Conservation Measure	All	Low	Mid	High*
Insulate roof	13 (15)	13 (6)	11 (7)	18 (2)
Reflective paint on roof	15 (19)	16 (9)	9 (6)	31 (4)
Reduce A/C use	53 (43)	25 (6)	62 (26)	73 (11)**
Cease A/C use	41 (29)	29 (6)	47 (18)	46 (5)
Disconnect water heater	81 (102)	71 (35)	86 (53)	93 (14)
Regulate water heater thermostat	31 (25)	22 (6)	35 (15)	33 (4)
Increase water heater insulation	7 (5)	12 (3)	5 (2)	0 (0)
Use lower Watt bulbs	82 (141)	88 (72)	79 (60)	60 (9)**
Use more efficient bulbs	54 (69)	49 (28)	57 (33)	62 (8)
Turn off lights	97 (173)	97 (80)	96 (76)	100 (17)
No hot water in wash	49 (70)	45 (26)	54 (36)	47 (8)
Use washer less/ larger loads	68 (94)	76 (44)	62 (41)	60 (9)
Use dryer less	52 (29)	26 (5)	59 (16)	80 (8)**
Use iron less	77 (123)	80 (57)	77 (58)	57 (8)
Use oven less	80 (99)	73 (37)	84 (48)	93 (14)

* Low--Less than or equal to the U.S. poverty level.
Mid--More than poverty level and less than or equal to four times poverty level.
High--More than four times the U.S. poverty level.

** Chi-square significant at .05.

TABLE 14
Conservation Measures by Income Group

Conservation Measure	Own	Rent
Insulate roof	19 (18)	0 (0)*
Reflective paint on roof	16 (18)	12 (4)
Reduce A/C use	55 (41)	39 (7)
Cease A/C use	48 (33)	20 (3)
Disconnect water heater	81 (81)	79 (30)
Regulate water heater thermostat	36 (26)	23 (5)
Increase water heater insulation	8 (5)	5 (1)
Use lower Watt bulbs	81(111)	87 (52)
Use more efficient bulbs	55 (56)	50 (20)
Turn off lights	96(137)	95 (56)
No hot water in wash	47 (53)	50 (23)
Use washer less/ larger loads	65 (75)	72 (31)
Use dryer less	54 (29)	42 (5)
Use iron less	77(101)	87 (40)
Use oven less	83 (82)	75 (30)

* Chi-square significant at .05.

Rico's close association with the United States and its electrification and development programs limit the confidence one can place in global generalizations.

Puerto Rican households expend a much larger proportion of their incomes for energy than do their U.S. counterparts. Low income households in Puerto Rico, as in many other localities, tend to pay a disproportionally large share of their incomes for energy than do better off households. To this end, the Commonwealth government has a lifeline subsidy for residential consumers who use less than 425 kwh monthly. As Puerto Rico has developed and as connection to the grid has become universal, all households including those with low incomes have acquired more electricity consuming devices. More than 70 percent of low income households possess washing machines, frost free refrigerators and color televisions, two devices which use substantial quantities of electricity. Most Low income households own several other electrical devices. The policy dilemma faced by Puerto Rico is to determine an appropriate cutoff point for the lifeline rate while considering the relationships this policy will have on increasing consumption and quality of life for the poor and on the island's near total dependence on foreign oil for generation. This dilemma may foreshadow situations to be faced by other oil dependent developing countries in the future.

The second critical policy matter illuminated by the data is the transportation situation on the Island. Without reasonable mass transit alternatives low income households must possess a motor vehicle, most often an automobile. These households must therefore expend exceedingly large proportions of their income for transportation.

If a subsidy is one policy avenue whereby a government decides to assist its less well-off population, the ideal policy tool is one which is highly target specific with little of the benefit being captured by outside groups. Mass transit, particularly in developing areas, often meets this condition because of disadvantages associated with traveling to and from by bus or train. Intra-city mass transit, the guagua, receives a significant subsidy, but this does little to address the needs of rural poor, or in providing long distance transport -- most of which is accomplished by publicos.

Lifeline subsidies also meet this condition if they are set at an appropriate level. The CEER data indicate that in Puerto Rico there is a relationship between electricity consumption and income. Therefore, a reasonably target specific lifeline electricity rate may be developed. A third energy source LPG might also be the target specific condition because LPG is predominately used as a cooking fuel by lower income households. However, LPG subsidies present a set of problems similar to electricity subsidies.

Finally, we have suggested elsewhere [32] that Puerto Rico's experience in rural electrification may provide an important model for other islands. That model is a centralized one, one well primed with capital, with programs to stimulate residential energy consumption at all income levels in both urban and rural settings. We recognize that the Puerto Rican situation is special: the price of oil may have been halved in the last two to three years, it is never-the-less relatively expensive. Oil was cheap when Puerto Rico underwent electrification. Puerto Rico, as eluded to above, also has numerous advantages in its relationship to the United States, which other islands do not have. That said, the expansion of electrification was dramatic, and was essentially complete by 1965. We have shown that in the 1980s, there has been another expansion, this time in the residential consumption of energy.

REFERENCES

[1] - Morales Carion, A., Puerto Rico: A political and Cultural History, New York, Norton, 1983.

[2] - Bonilla, F. and R. Campos, "Up by the Bootstraps: Ideologies of Social Levitation." Interciencia, 1986, 11.

[3] - Smith, L., "Up by the Bootstraps ..." Interciencia, 11, 1: 32-3, 1986.

[4] - Segal, A., "The Debate over Puerto Rico." Interciencia, 11, 4: 195-6, 1986.

[5] - Silva Michelena, J.,"Comentarios sobre up by the bootstraps." Interciencia, 11, 4: 194-5, 1986.

[6] - US Department of Commerce, Statistical Abstract of the United States 108th edition Washington, DC, 1987

[7] - World Bank, World Development Report 1987. NY: Oxford Univ. Press, 1987.

[8] - Koehler, Jr., W. and J. Bonnet, Jr.,"The Status of Renewables in the Caribbean." Proceedings of the Energex Conference, New Forms Renewables, Conservation, Regina, Saskatchewan, Canada, May 1984.

[9] - Koehler, Jr., W., "Renewable Energy in the Caribbean." Energy Conversion and Management, Suppl. 1, 1987.

[10] - Puerto Rico Office of Energy, "Una Estrategia Energética para Puerto Rico." San Juan, October 1987.

[11] - Latimer Torres, E., La Autoridad de Energia Electrica y los Sistemas de Alumbrado en Puerto Rico (apuntes historicos). Colección Puertorriqueña, San Juan, 1983.

[12] - Puerto Rico Autoridad de Fuentes Fluviales, Electricidad para Todos, un Informe sobre los Logos en la Electrificación de la Zona Rural de Puerto Rico, San Juan, 1979.

[13] - Brown, H., Decentralizing Electricity Production. Yale Univ. Press, 1983.

[14] - Collier, H., Developing Electric Power: Thirty Years of World Bank Experience. Johns Hopkins Univ. Press, 1984.

[15] - McDonald, J.S.,"The Impact of Rural Electrification in Thailand." Southern Political Science Assoc. Savannah, GA, November 1984.

[16] - Munasinghe, M.,"Planning for Electrical Power: Costs and Technologies." World Bank Reprint Series No. 149, 1980.

[17] - Smith, D., "Rural Electrification on Village Energization." Interciencia, 5, 2, 1980.

[18] - Papua New Guinea Department of Minerals and Energy, Energy Policy and Planning for Papua New Guinea. Konedobo, 1979.

[19] - Urrutia, R., "Electrificación Rural en Puerto Rico." Autoridad de las Fuentes Fluviales, San Juan, 1965.

[20] - Puerto Rico Office of Energy, Informe de la Situación Energética de Puerto Rico, Año Fiscal 1983-84. San Juan, 1984.

[21] - Rodríguez, E., W. Ocasio, S. Torres, F. Zalacaín, and S. Lugo, Distributional and Socioeconomic Impacts of Electricity Price Increases on the Puerto Rican Population. CEER Report, San Juan, 1983.

[22] - Iriarte, M. and R. Sardina, "Energy Analysis and Socioeconomic Considerations for Puerto Rico." CEER Report X-72, San Juan, May 1980.

[23] - López Roman, H.,"Conservación de Energia en Puerto Rico: Analisis Teorico-empirico de Corto Plazo para el Caso de la Electricidad." CEER Report, San Juan, 1985.

[24] - Puerto Rico Electric Power Authority, Prospectus. San Juan, October 15, 1987.

[25] - US Department of Energy, Residential Energy Consumption Survey, Housing Characteristics 1984. DOE/IEA-0314(84), Washington, DC, 1986.

[26] - Bonnet, Jr., J. and J. Parrotta, "High-Tonnage Cane for Multiple Uses", Proceedings of Energex 88, Tripoli, Libya, in press.

[27] - Sasscer, D. and T. Morgan, "The Energy Integrated Farm System in Puerto Rico, Final Report." CEER Report O-221, San Juan, 1986.

[28] - Pool, R., "Solar Cells Turn 30." Science, 241, 4868, August 9, 1988, pp. 900-1.

[29] - US Census Bureau, Money Income of Households, Families, and Persons in the United States: 1985 (P-60, No. 156) Washington, DC, 1987.

[30] - Puerto Rico Electric Power Authority, Planning and Research Division, Survey on the Use of Electric Appliances by Residential Customers in Puerto Rico. San Juan, February, 1983.

[31] - US Bureau of Labor, CPI Detailed Report: September 1987 Washington, DC: U.S. Department of Labor.

[32] - Koehler, Jr., W. and J.S. McDonald, "Household Energy Consumption, Development, and Insular Nations: A Puerto Rican Case." Proceedings from the International Symposium Energy Options for the Year 2000, Wilmington, DE, September 1988.

[33] - US Census Bureau, 1980 Census of Population: General Social and Economic Charateristics: Puerto Rico, PC80-1-c53aP.R., Washington, DC, 1984.

[34] - US Census Bureau, 1980 Census of Housing: Characteristics of Housing Units; Part 53: Puerto Rico, HC80-1-A53, Washington, DC, 1984.

SECTION II

CONVERSION TECHNOLOGY AND MANPOWER

COAL GAS FIRED MHD POWER PLANTS

MOHIBULLAH* AND M.A. JANI*
Z.H. COLLEGE OF ENGINEERING AND TECHNOLOGY
ALIGARH MUSLIM UNIVERSITY, ALIGARH-202001
INDIA

ABSTRACT

Now-a-days thermal power plants are major sources of power generation and the maximum efficiency achieved from advanced conventional power plants is around 30-35 percent. With coal fired Magnetohydrodynamic (MHD) plants this efficiency is increased around 20-40 percent compared to above power plants.

The present paper describes the world developments in coal gas fired MHD power plants and compares the merits and demerits of adopting this technology for developing countries. Cost and economy are also focussed. The electrical characteristics of a test facility is also described using a particular quality of coal with added seed material. Various applications in space and defence are also included in this paper.

1. INTRODUCTION:

With growing energy crisis new sources of energy have to be found, at the same time, efficient use of existing sources is essential. World technological development on MHD has been on a relatively intense basis during the last 20 years.

* Dr. Mohibullah, Reader, Department of Electrical Engg.
* Prof. M.A. Jani, Principal
Z.H. College of Engineering & Technology,
Aligarh Muslim University, Aligarh-202002, (India)

The area in MHD development that has received the maximum international attention and has a potential for power generation is the MHD conversion in fossil fuel based systems. In spite of advent of other energy sources coal still remains the most important fuel for power generation all over the world and about 79 percent of electricity is supplied by thermal power plants. In mid seventies, Energy Conservation Alternatives Study (ECAS) was conducted and the results proved that open cycle, coal fired, direct pre-heat MHD systems have potentially one of the highest overall efficiency and also one of the lowest cost of electricity (COE) among the various advanced power plant concepts using coal or coal derived fuels. For better efficiency and cheaper electrical power generation a MHD generator and associated components could be coupled to an existing conventional steam plant as a topping cycle, and could be optimised for full load operation as a base load plant. However, occasional demands for part load operation may also occur during emergencies.

A first stage coal fired MHD plant is projected to achieve a cycle efficiency of 48 to 52 percent compared to conventional plant of about 29 to 35 percent and second stage MHD generation is expected with an over all efficiency of 60 percent. The consumer cost of electricity per kwh with MHD system will be approximately 18 to 20 percent lower than the conventional thermal power plants and the fuel saving between 20 to 30 percent with less heat wastage per unit of useful power.

In addition to cost and efficiency considerations, this technology is also good for commercial applications because of its better thermal and air pollution control features. The improved efficiency in MHD plants implies a reduction of pollutents. They are reduced further with the emmission control schemes. The hazardious constituents of sulphur and nitrogen are removed from the flue gases because of high temperature and pressure of the MHD process. Because of these potentials Magnetohydrodynamic power generation from the fossil fuels is emerging as most effective energy conversion method.

The electrical characteristics of an MHD generator is different from the normal two terminal generators because an MHD generator is a multi-electrode configuration. These characteristics are different for each electrode pair for a given quality of coal, seed material, velocity of gas and magnetic field. The electrical characteristics for different modes of loading are given. As an energy device, the MHD generator has characteristics e.g. compactness, simplicity and high power density which make it specially suitable for a variety of special applications particularly in the military area. This has been realized early in the United States, and by the late 1950s, several programmes exploring special applications were initiated.

2. INTERNATIONAL DEVELOPMENTS:

The most effective use of MHD with coal is to design MHD generator as a topping cycle for a steam turbine plant as shown in figure 1. In such a system the exit gas from the channel will be used for production of steam in conventional power systems. Since the cost of coal fired conventional plants is steadily increasing because of increased constraints on atmospheric pollution, MHD system will be more economical as it is environmentally excellent system. The electrical conductivity of the fossil combustion gases, potassium or sodium or cesium etc. is added as seed. NASA coordinated the findings of Energy Conservation Alternatives Study (ECAS) who used the common ground rules concepts for advanced power plants fired by coal or coal-derived fuels. The results of this study proved that open cycle, coal fired direct pre-heat MHD systems have potentially one of the highest coal pile to bus-bar efficiency and also one of the lowest cost of electricity (COE). Recent developments in USSR and USA have substantially improved the credibility of open cycle coal gas based MHD power generation.

World developments on MHD have been on relatively intense basis during the last fifteen years, although the budgets involved have never been more than a few percent of the amounts devoted to the development of nuclear reactors. The major countries that have started commercial MHD programmes are USSR, USA, Japan, Australia, India, Poland, China and Finland.

2.1. MHD Programme in USSR:

The MHD programme in USSR is the most extensive and largest in the world. It ranges from advanced research to the setting of the first demonstration plant U-25 and completion of the first 500 MW steam binary cycle power station.

At present three major trends in the development of coal-fired MHD are under consideration:

(i) MHD power plants with direct combustion of coal in special combustors and maximum slag removal.

(ii) MHD power plants with direct combustion of coal without slag-removal in the combustor.

(iii) MHD power plants utilizing the products of coal gasification and processing.

One of the major stages in the Soviet programme aimed at the development of MHD power plants with direct coal, combustion and maximum slag removal in the combustion chamber is the development of the integrated coal fired U-25 G. The U-25 G facility is rated for the following parameters [1] .

Working fluid	-	Coal combustion products
Oxidizer	-	Air enriched with oxygen
Seed	-	50 percent aqueous solution of potassium carbonate
Flow rate of combustion products	-	5 kg/S
Flow rate of coal	-	0.8 kg/S continuous operation, 1.2 kg/S short term operation

2.2. MHD Programme in USA:

A number of test and experimental facilities were set up in USA like CDIF, AVCO, CFFF. Apart from its own MHD programmes, a number of cooperative programmes with other countries are being carried out. Fairly substantial support has been given to Polish coal-fired facility which has tested various US coals.

Gilbert/Commonwealth has conducted a series of investigations on commercial size MHD/steam power plants. For the economic comparisons, power plants with thermal inputs of both 1165 MW_t and 2330 MW_t were evaluated [2] .

2.3. MHD Programme in other countries:

In Japan a coal-fired MHD system is being tested at the ETL Mark VII MHD Facility with the objective of comparing the generation characteristics [3] . China has already constructed a direct coal fired MHD test facility JS-II [4] . Australia, India, Poland, Netherlands, Finland, Italy are also progressing in coal based power plants.

3. Cost and Economy:

Economic evaluations can be made in advance of the developments of this technology. The cost of MHD-steam power plants has been shown to be competitive with those of the corresponding conventional fossil fired plants when the cost of pollution control is included. Because of higher efficiency and, therefore, better fuel utilizatin operating costs are less. The bus bar cost of electricity generation by MHD is generally projected to be as much as 20% lower than conventional coal fired plants. In terms of coal saving, it is estimated that one million tons of coal can be saved per 1000 MW of electrical power generated.

Another reason for the cost reduction is the increased efficiency of conversion because MHD is an environmentally excellent system. The fuel combustion temperature is so much high in an MHD system that the combustion is more complete. This reduces the harmful emissions from the system by more than 90 percent.

4. ELECTRICAL CHARACTERISTICS:

An analysis programme developed by Matair [4] was modified to take into account the Hall effect and electrical

characteristics were obtained for both Faraday and diogonal modes. The model includes the wall skin friction and heat transfer to the walls. The characteristics are obtained for a constant mass flow rate (0.3 kg/s) of plasma in the duct. At the inlet of the MHD duct, the stagnation temperature of the plasma is assumed to be equal to the stagnation temperature at the combustor. The pressure at the duct exit is determined from the exit stagnation pressure of the diffuser with the assumed diffuser efficiency of 0.7. The electrical loading of the generator is taken into account by computing the current density "J" from the specified current or the voltage of an electrode pair [5]. The above developed programme was solved by a two step time marching, finite difference Mac-Cormack algorithim which can handle subsonic supersonic and transonic flows [4, 6]. The electrical characteristics were obtained for the following data.

4.1. Data for the calculation of electrical characteristics:

Duct	Linearly diverging from 3.2 cms to 4.2 cms in width. Length = 1 metre
Nozzle	Width = 3.3 to 3.2 cms Length = 0.1 metre
Diffuser	Width = 4.2 cms Length = 0.4 metre

The height of nozzle, duct and diffuser is constant at 0.1 metre.

Magnetic field	3 Tesla
Diffuser efficiency	0.7
Electrode voltage drop	40 volts
Electrodes	20 pairs, pitch = 5 cm
Fuel	Coal seeded with KOH
Inlet temperature	$2800^{o}K$
Exit stagnation pressure	1.1×10^{5} pa
Mass flow rate	0.3 kg/s
Loading parameter	varied between open circuit and short circuit
Finite difference increments	$= \Delta x = \frac{Z}{N-1} = 5$ cms $\Delta t = \frac{0.6 \quad x}{\lvert u_{max} \rvert + C_{max}}$

"Δt" was set so as to obey the courant condition for the numerical stability of the Lax-Wendroff algorithm. The terms u_{max} and C_{max} are the values of the maximum gas velocity and maximum sonic velocity in the duct at any time.

With the above data the modified computer programme [4] was used to calculate the V-I characteristics of the generator. The sample out puts are shown in table A-1 and

A-2 in appendix A. The programme takes into account cross sectional area at N points when the duct is divided into (N-1) equal subsections of width Δx. The initial distribution of fluid state is specified for each point $i. \Delta x$ with i ranging from 2 to N. The gas used for the simulation of real gas magnetohydrodynamic generator flows consists of the products of the combustion of coal with a stoichiometric amount of oxygen, equal amount of nitrogen and 1.5 percent by weight of potassium hydroxide (KOH) which is used as seed material.

5. APPLICATIONS:

The earlier conferences on MHD discussed papers and research into direct conversion for extraterrestrial applications, including MHD propulsion, on board power generation, and plasma processes. Must of the early advanced MHD research in liquid metal systems and high temperature applications, in fact, has begun in the late 1950s with an eye toward full-scale manned solar expeditions.

Although the goals and funding for the NASA space programme were modified and long-term human space flight was removed from the agenda, the space programme and its laboratories and contractors have continued to play an important role in MHD research.

A conference held at the NASA Lewis Research Centre in cleveland, Ohio on "Plasmas and Magnetic Fields in propulsion and Power Research" in October 1969 discussed the importance of MHD and fusion plasma research on propulsion and power systems for aircraft and spacecraft. New or improved propulsion and power concepts and systems were needed.

NASA Lewis reported at the conference that it had tested steady-state radiation cooled MPD thrusters at power levels from 100 watts to 40 kilowatts. Using ammonia as the propellent, the thrust was developed primarily by magnetic nozzle effects. The data showed that most of the ion acceleration occurred in magnetic nozzle region. In summarizing their results, the scientists reported that they had fair success in making plasma measurements and that the complexity of the phenomena required more diagnostic study for a better understanding of the device's operation.

At the same conference, other NASA-Lewis researchers reported on progress in closed-cycle MHD work for power generating applications for utilities, concluding that such systems, primarily those coupled with nuclear reactors, would be optimal for on-board power in space.

During the late 1960s and early 1970s, Richard Rosa developed an application of his nuclear cavity reactor for space propulsion. This complex system involves heating the liquid hydrogen by the exhaust heat of an MHD generator using a nuclear heat source. Electric power produced in the MHD generator would provide additional energy input to heat the propellent and provide onboard power.

The heated propellent can be further expanded by use of a turbine powered by the MHD generator. Since the primary optimizing criterion for a space-power system is weight, the compactness and weight-to-power ratio gained in an MHD system make it very appropriate for spacecraft applications.

5.2. Portable Power Sources

A unique characteristic of MHD power generation is that the generator can be of any size, although efficiency is lower in smaller power units. Efficiency is not the primary consideration in portable applications for emergency stand-by, or mobile requirements, including temporary power for scientific experiments in isolated areas.

Soviet Academician Velikhov began an experimental programme in 1973 to operate a series of small, portable MHD generators. Called the Pamier series because they were designed and built for conducting scientific geophysical experiments in the Pamir Mountains, these portable MHD generators are commercially operable MHD systems.

Velikhov applied his experience with MHD to the needs of geological scientists. For years geologists had been probing the earth by drilling boreholes into the earth's crust to measure movements in order to predict earthquakes. The scientists had studied seismic waves, but these carry information only on the elasticity and mechanical properties of matter - "appropriate for billiard balls, but not the earth," as a Soviet scientist put it.

It was known that electromagnetic sounding methods would yield additional information but this technique was limited by the strength of the sounding signal from the generators used in the experiments. Natural earth currents and interference from industrial power production required the operation of self-contained generators that could produce a strong, independent signal.

In 1973, the Kurchatov Laboratory sent the Pamier MHD generator from Moscow to begin operation as part of the equipment of the Institute of Physics of the Earth of the Soviet Academy of Sciences. The initial experiments showed that changes in the electrical conductivity of the rocks of the earth's crust begin two or more months before a strong quake.

According to Soviet computations, 30 to 50 such MHD apparatus could adequately cover all the seismically active regions of the Soviet Union. The series of sounding units would have to be linked through a computer bank to process the recordings of the network of receivers and to monitor any changes recorded. This system could effectively forewarn the entire nation of an impending serious earthquake.

5.3. Other Applications:

Relatively small and portable MHD generating systems are commercially used for peak power supply. In periods of high demand, small and generally inefficient power generating units are brought into service to meet demand peaks. These systems burn expensive petroleum or natural gas because these fuels can be stored and transported easily. A small MHD system which could be a standby will solve the problem because it burns less expensive coal.

In emergencies, the most important criterion is start-up time. If, for example, the power on the grid should fail, a MHD generator could provide emergency power for a hospital within minutes of ignition. There is no delay waiting for fuel to be burnt, water heated to produce steam and turn turbines and so forth. The MHD generator could go from cold start-up to full power in seconds.

Short-term MHD power could also be provided to remote regions for critical usage or to supplement baseload power systems in operation.

6. CONCLUSION:

This paper describes the suitability of MHD power generation for economic use of coal with less environmental pollution and heat wastage per unit of power generated. Various international developments are described briefly. Most of the developed and developing countries have started the research and developmental activities and an early commercialization of this technology is expected soon. Nations with limited natural resources like Japan are in search of more efficient power generation with MHD technology. A brief description of electrical characteristics of a MHD generator is given. The coal has been used as the working medium with potassium Hydroxide (KOH) as seed. The sample calculations of voltage, current, power and Hall voltages are presented in a tabular form. These tables give an idea as to how the electrical characteristics vary along the channel.

The characteristics of an MHD generator like its compactness, simplicity and high power density makes it specially suitable for a variety of applications. The detailed applications are described.

Because of its above promising potentials mentioned this technology of power generation should be given due consideration specially in the developing and the under-developed countries.

7. REFERENCES:

[1.] Kirillin, V.A. and et al., "Principle Directions of Investigations and Development Works on Elaboration of a Coal Fired MHD Power Plant in USSR", Specialists Meeting on Coal-fired MHD Power Generation, Sydney, Australia, Nov. 4-6,1981.

[2.] Lawit, R.L. and et al., "Recent Studies of MHD systems: Baseline Plant and Part load Performance", Proceedings of 22nd Symposium on Engineering Aspects of MHD, Mississippi, USA, June, 26-28,1984.

[3.] Kusaka, Y., and et al., "Experiments of ETL Mark VII MHD Facility", Proceedings 22nd. Symposium on Engineering Aspects of MHD, Mississippi, USA, June 26-28, 1984.

[4.] Vinogradova, G.N. and et al., "Numerical study of Unsteady Processes in a Faraday MHD Generator", Journal of High Temperature, U.S.S.R., Vol. 19, No. 1, 1981.

[5.] Matair, S., and et al., "Stability Study of an Inverter Controller for an MHD Generator". Proceedings of 22nd Symposium on Engineering Aspects of MHD, Mississippi, USA, June 26-28,1984.

[6.] Oliver, D.A., "The Time Dependent MHD Generator, Proceedings 14th Symposium on Engineering Aspects of MHD, Tullahoma, Tennessee, USA, 1974.

n

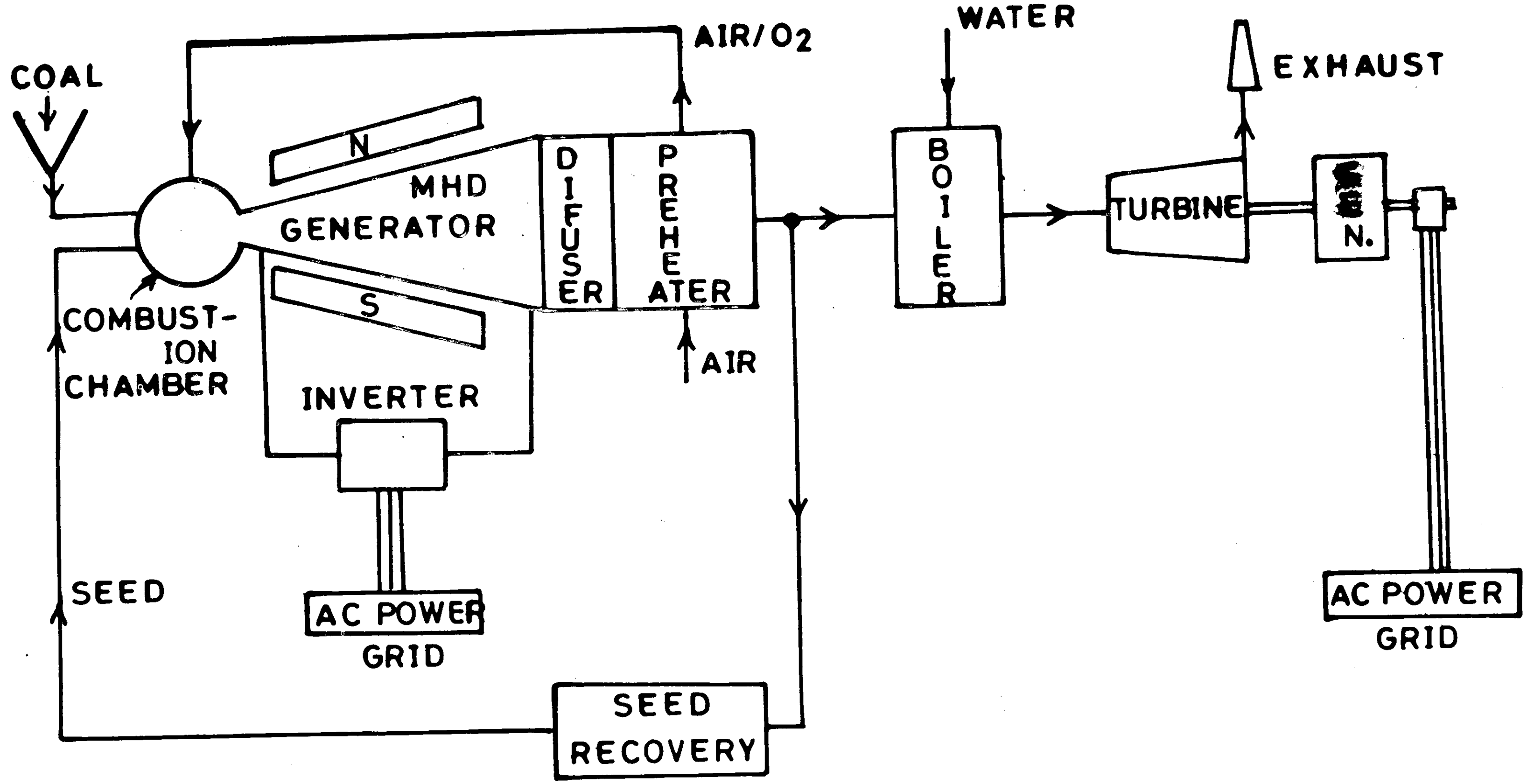


FIG.1. SCHEMATIC OF MHD-STEAM CYCLE POWER PLANT.

APPENDIX A

TABLE A-1. SAMPLE OUTPUT OF COMPUTER PROGRAMME (Faraday Mode)

ELECTRODE (No.)	POWER (Watts)	CURRENT (Amps)	VOLTAGE (Volts)	INTER RESIST (Ohms.)	LOAD FACTOR (K)
1	470.44	10.37	45.33	4.37	.50
2	497.98	10.57	46.19	4.37	.50
3	503.12	10.70	47.02	4.39	.50
4	490.32	10.66	46.01	4.32	.50
5	497.09	10.80	46.02	4.26	.50
6	462.31	10.48	44.11	4.21	.50
7	429.76	10.61	40.50	3.82	.50
8	310.93	11.15	45.92	4.11	.50
9	439.68	10.50	41.88	3.99	.50
10	503.84	11.27	44.69	3.96	.50
11	514.06	11.04	46.57	4.22	.50
12	480.60	10.61	40.57	3.82	.50
13	485.95	11.24	43.22	3.84	.50
14	450.91	10.97	41.09	3.74	.50
15	443.55	10.91	40.66	3.73	.50
16	414.30	11.02	37.61	3.41	.50
17	491.42	11.58	42.42	3.66	.50
18	443.31	11.17	39.67	3.55	.50
19	475.19	11.54	41.18	3.57	.50
20	462.37	11.51	40.16	3.48	.50

TABLE A-2. Sample output computer programme
(Diagonal Mode)

ELECTRODE (No.)	POWER (Watts.)	CURRENT (Amps.)	VOLTAGE Volts)	INTER RESIST (Ohms.)	LOAD FACTOR (K)	HALL (Volts)	BETA (B)
1	627.91	10.68	58.79	5.50	.50	39.23	1.29
2	662.86	10.76	61.61	5.73	.50	41.24	1.29
3	705.82	10.95	64.43	5.88	.50	44.43	1.32
4	684.42	10.88	62.88	5.78	.50	43.37	1.32
5	721.09	11.15	64.69	5.80	.50	45.73	1.34
6	709.81	11.14	63.71	5.72	.50	45.24	1.35
7	738.19	11.35	65.02	5.73	.50	47.16	1.37
8	735.95	11.40	64.57	5.67	.50	47.23	1.38
9	757.85	11.58	65.46	5.65	.50	48.76	1.40
10	760.30	11.65	65.27	5.60	.50	49.43	1.41
11	779.93	11.82	65.99	5.58	.50	50.54	1.43
12	785.73	11.91	65.99	5.54	.50	51.14	1.44
13	802.95	12.06	66.56	5.52	.50	52.43	1.46
14	811.94	12.17	66.71	5.48	.50	53.25	1.48
15	830.19	12.35	67.23	5.44	.50	54.55	1.50
16	841.01	12.46	67.50	5.42	.50	55.56	1.52
17	861.94	12.67	68.04	5.37	.50	56.96	1.54
18	870.97	12.73	68.42	5.37	.50	58.11	1.56
19	894.93	12.98	68.95	5.31	.50	59.63	1.58
20	999.32	12.94	69.48	5.37	.50	60.93	1.60

IMPROVEMENT IN PERFORMANCE OF GAS TURBINE REHEAT CYCLE PLANT USING FIXED BED REGENERATOR BY STEAM ADDITION

ASGHARALI INAYATHUSAIN *
Shri G.S. Institute of Technology & Science
INDORE 452003 (India)

and

SAIFUDDIN ASIF
Shri G.S. Institute of Technology & Science
INDORE 452003 (India)

ABSTRACT

Improvement in the performance of stationary gas turbine plants using fixed bed regenerators, wherein waste steam is mixed with combustion air, is predicted. It is estimated that the overall efficiency of the reheat cycle is improved by 10 to 15 per cent, and a 5 to 10 per cent increase in work output is attainable by the addition of 2 to 3 per cent of steam. The effects of pressure ratios, compressor and turbine polytropic efficiencies and maximum cycle temperatures are studied. It has been predicted that higher the pressure ratios, lower the compressor/turbine efficiencies, or lower the turbine inlet temperatures, more is the improvement in efficiency with steam addition over that without injection.

1: INTRODUCTION :

The beneficial use of rotary regenerators for improving the cycle efficiencies has been recognised for the automotive vehicles and aircrafts. However, except for some experiments the use of fixed-bed regenerators in gas turbine plants [1] has not received any attention.

The use of gas turbine plants of large capacities for power generation is becoming common [2] . The recovery of heat from exhaust of these plants can be effectively achieved in fixed bed regenerator also. And, if some definite advantages of fixed bed regenerators are projected, it is possible to recommend their use in stationary gas turbine power plants.

It has been reported [3] that the use of steam injection to combustion air, before entry to heat exchanger, in a simple gas turbine cycle plant having fixed bed regenerators increases the cycle efficiency and specific work output. This has been possible because of(i) improvement in heat exchanger thermal ratio [4, 5] , and (ii) increased flow rate.

---

* Presently working in HIMEE HOON (Libya)

In a gas turbine reheat cycle, the exhaust gas temperatures are still higher [6], and there is scope for more heat recovery through thermal regenerator. Even after heat recovery the exhaust gas temperatures would be sufficient to generate a large quantity of waste steam.

The present paper is devoted to predict the effect of steam addition to combustion air on the performance of reheat cycle gas turbine plant using fixed bed regenerator. The complete cycle including the thermal regenerator has been simulated on a digital computer. Thus the effect of steam addition on the regenerator thermal ratio is automatically considered.

The data for investigation are taken from an existing plant. The improvement in cycle efficiency with steam addition has been predicted for different pressure ratios, polytropic efficiencies and maximum cycle temperatures.

2: METHOD OF ANALYSIS :

The method of analysis used for the present work is an extension of the method developed by the authors in their earlier paper [3], for the cycle without reheat. Two stage compression with intercooling is employed. The compressor and turbine isothermal efficiencies are computed from small stage (polytropic) efficiencies. The pressure drops in the components are considered, and the combustion efficiencies in the combustion chamber and the reheater are calculated as functions of the respective air fuel ratios [7]. Separate compressor turbine is employed, and reheating is done only once upto the maximum cycle temperature. The complete cycle is shown in Fig. 1. The method of analysis [3] is suitably modified to incorporate all the above effects. The variable specific heats of air, steam and gases are also accommodated in the analysis.

3: RESULTS AND DISCUSSIONS :

The data for present investigations are as below :

Air inlet temperature	:	300 K
Maximum cycle temperature, Tmax	:	1400 K
Air inlet pressure	:	101.3 kPa
Fuel composition (by wight)		
Carbon	:	84 per cent
Hydrogen	:	16 per cent
Lower heating value of fuel	:	42.1 MJ/kg
Compressor Pressure Ratio, r_p	:	8 : 1
Polytropic efficiency of compressor and turbine, η_p	:	0.85
Effectiveness of intercooler	:	0.75

Pigeon hole type of chequers have been used, and the passages are approximated by rectangular channels. The regenerator parameters are as below:

Mass of each chequer	:	101 tonnes
Specific heat of chequer material	:	1.05 kJ/kg K
Ratio of heating area to flow area	:	24.4 : 1
Semi-thickness of channel wall	:	0.0318 m
Mean beam length	:	0.1428 m
Hydraulic diameter	:	0.1679 m
Thermal conductivity of chequer material	:	1.68 W/m K
Thermal diffusivity	:	4×10^{-7} m^2/s
Heating period	:	600 s
Cooling period	:	1200 s
Pressure drops,		
through intercooler	:	11 kPa
through combustion chamber and reheater	:	15 kPa
through regenerator, gas side as well as air side	:	18 kPa

The problem has been solved on ICL 2960 computer for steam quantities varying from 0-12 per cent by weight. Dry saturated steam is assumed to be generated at 101.3 kPa, and is mixed with air at the entry to compressor.

As has already been established [4], with the addition of about 2-3 per cent steam, there is a significant increase in preheat temperature. Above this quantity, the increase is very slow, and after about 6 per cent, there is very little increase in the preheat temperature. With increase of preheat temperature the fuel-air ratio is expected to decrease by adding steam to combustion air.

Fig. 2 compares the computed values of fuel-air ratios for steam addition from 0 to 12 per cent for the simple cycle and the reheat cycle. It can be seen that, in both cases, the fuel-air ratio decreases very rapidly with upto 2 per cent steam addition. For the simple cycle the decrease is from 0.0149 to 0.0135 (or 9.4 per cent). For the reheat cycle the corresponding decrease is from 0.0145 to 0.0128 (or 11.7 per cent). It then decreases slowly, and after about 3 per cent of steam addition it starts increasing. The reason for such a trend is discussed in Ref. [3] .

The steam added to combustion air also expands with the gases in the turbine, increasing specific work. The effects of steam addition on the cycle efficiency, and specific work output are plotted on Fig. 3, for the considered example. For the simple cycle, the efficiency increases from 27.18 per cent at no steam addition to 30.5 per cent with 3 per cent steam

addition. The corresponding values for the reheat cycle are 28.58 per cent and 32.12 per cent respectively. The specific work output increases from 0.557 to 0.587 (or 5.4 per cent) without reheat, and from 0.685 to 0.715 (or 4.4 per cent) with reheat. It is evident that the improvement in efficiency for reheat cycle is greater, whereas that in the specific output for the simple cycle is greater.

After about 3 per cent steam addition, the relative increase in thermal efficiency and specific output is slow, and hence it is not beneficial to add steam greater than about 3 per cent.

With the same data as above, the cycle efficiency is plotted for pressure ratios of 4, 6 and 8 in Fig. 4. It may be noted that the increase in cycle efficiency with addition of 3 per cent steam is 8.77 per cent with a pressure ratio of 4 and 10.34 per cent with a pressure ratio of 8. Thus the beneficial effect of steam addition increases with increase in pressure ratio.

The effect of polytropic efficiency is plotted in Fig. 5, while Fig. 6 shows the effect of maximum cycle temperatures Tmax. From these figures, it can be observed that the beneficial effects of steam addition is slightly more at lower component efficiencies, and at lower values of Tmax.

4: CONCLUSION :

Addition of upto 3 per cent steam is most beneficial to increase the thermal efficiency and output of reheat cycle steam power plant. Hence it is worthwhile to use fixed bed regenerators on stationary gas turbine plants. The requisite injection steam may be generated from hot gases leaving the regenerator. Scope for further work lies in conducting experiments on existing plants by installing fixed bed regenerators. There may arise certain practical difficulties, but these have to be overcome.

REFERENCES :

1 - Welsh, R.J., and et.al., The Gas turbine Mannual 2nd edn. p. 108, 1955.

2 - News Report, Diesel Engineering. Vol. LXXIII, No. 795, p. 243, Winter 1977.

3 - Khandwawala, A.I., and et.al., "Prediction of the Effects of Steam Addition on Performance of Gas Turbine with Fixed-bed Regenerators", Heat Recovery Systems 4, pp 1-8, 1984

4 - Khandwawala, A.I., "Thermal Performance of Regenerators and Waste Heat Recovery", Ph.D. Thesis, I.I.T. De;hi, 1981.

5 - Chawla, O.P., and et.al. "Thermal Performance of Regenerators and Waste Heat Recovery", International Journal Heat Mass Transfer, 24 pp. 1793-1800, 1981.

6 - Cohen, H., and et.al., Gas Turbine Theory, E.L.B.S. and Longman Group Ltd., 1978.

7 - Ushiyama, I., and et.al., "Theoretically estimating the performance of gas turbines under varying atmospheric conditions". Journal Engg. Power, January, pp 67-89, 1976.

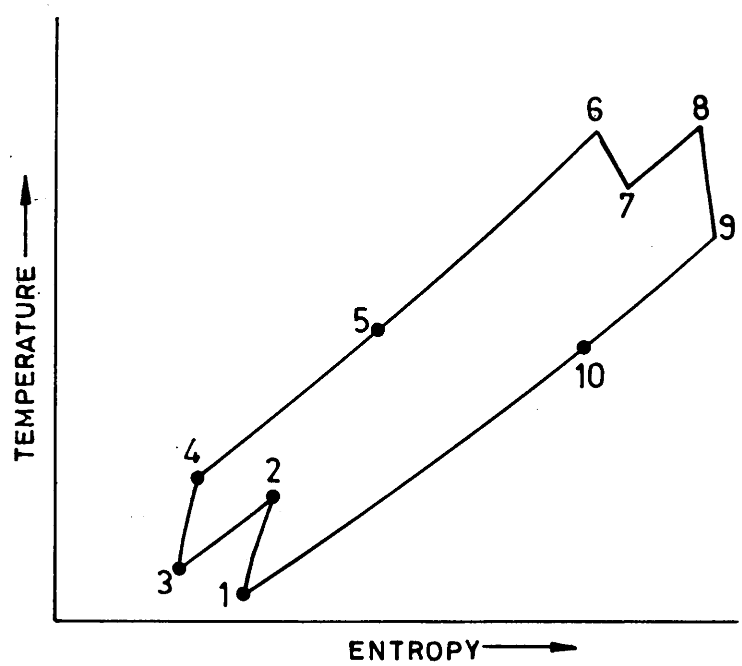


FIG.1. TEMPERATURE ENTROPY DIAGRAM FOR REHEAT CYCLE

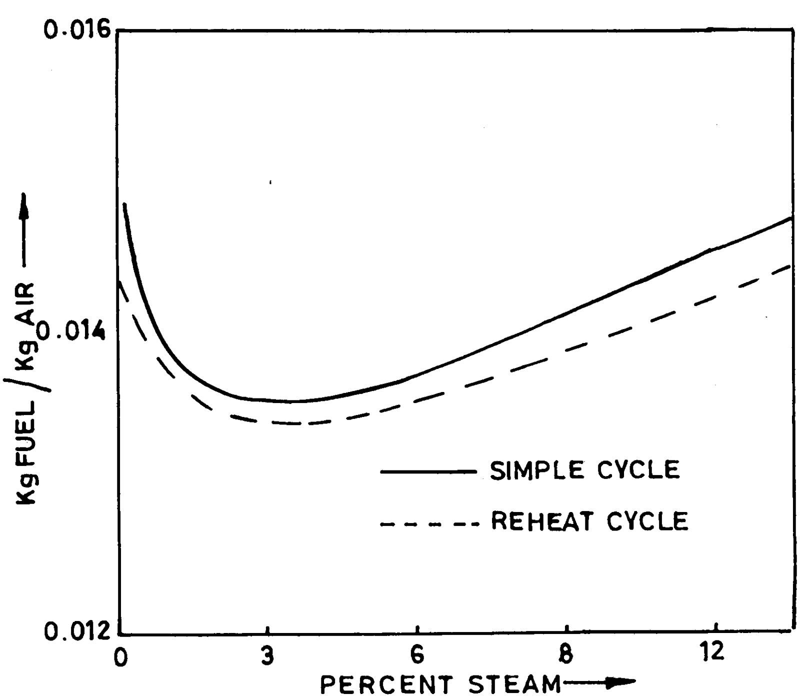


FIG. 2. EFFECT OF STEAM ADDITION ON FUEL-AIR RATIO.

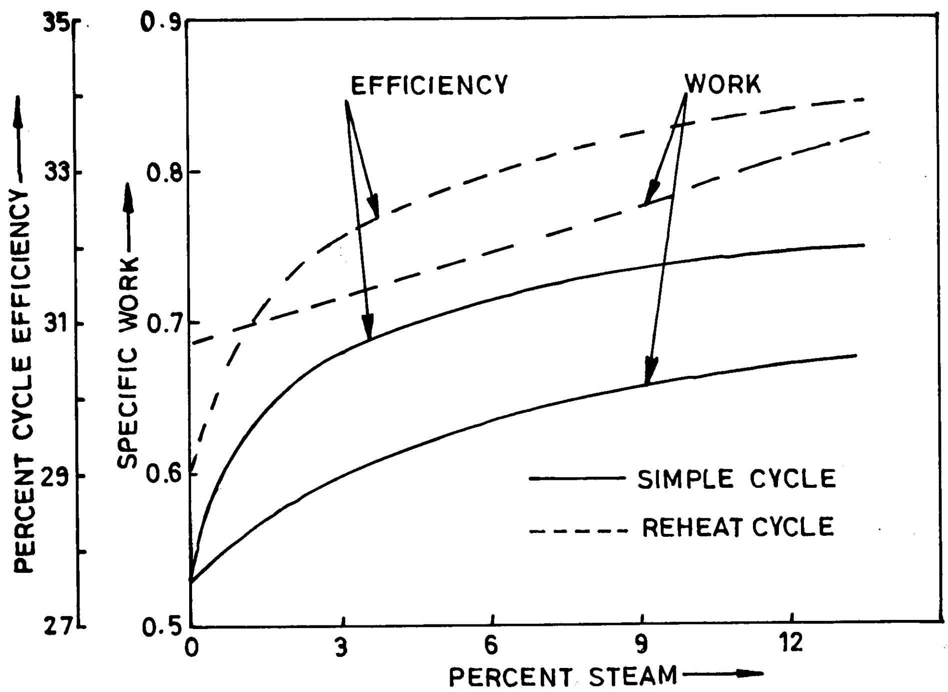


FIG. 3. EFFECT ON CYCLE EFFICIENCY AND WORK OUTPUT

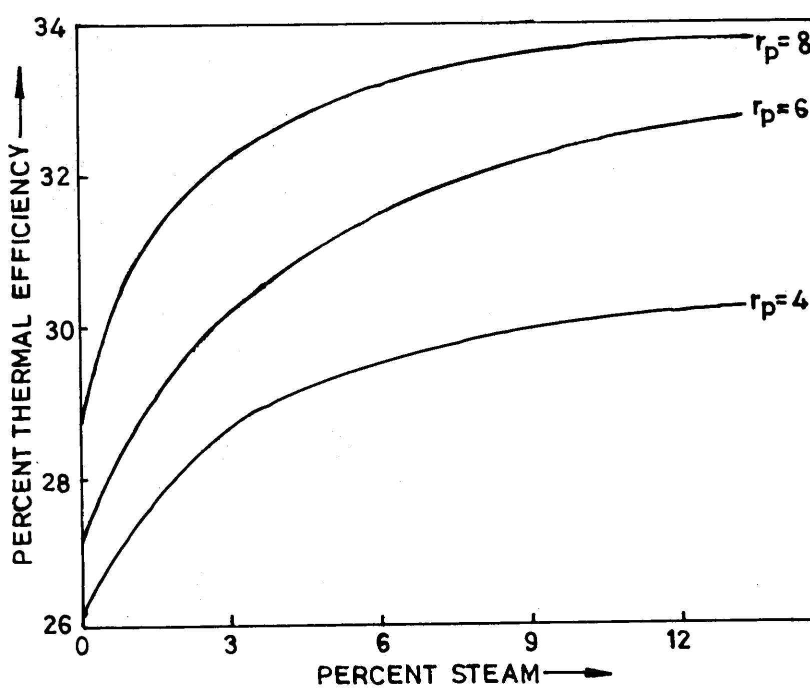


FIG. 4. EFEECT ON CYCLE THERMAL EFFICIENCY FOR DIFFERENT PRESSURE RATIOS.

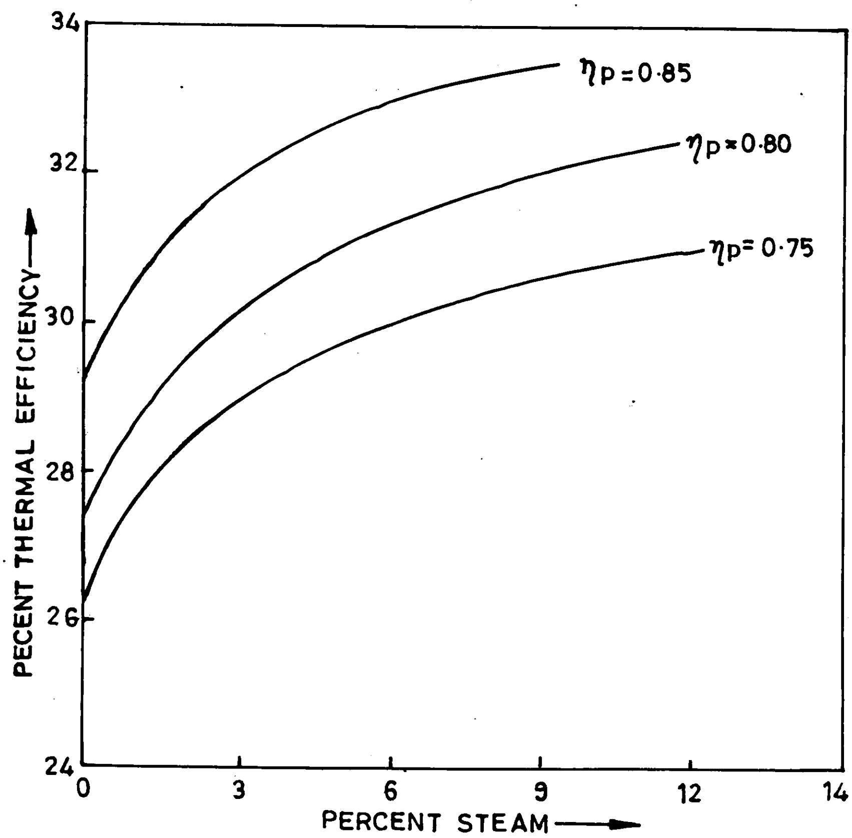


FIG. 5. EFFECT ON CYCLE EFFICIENCY FOR DIFFERENT POLYTROPIC EFFICIENCIES.

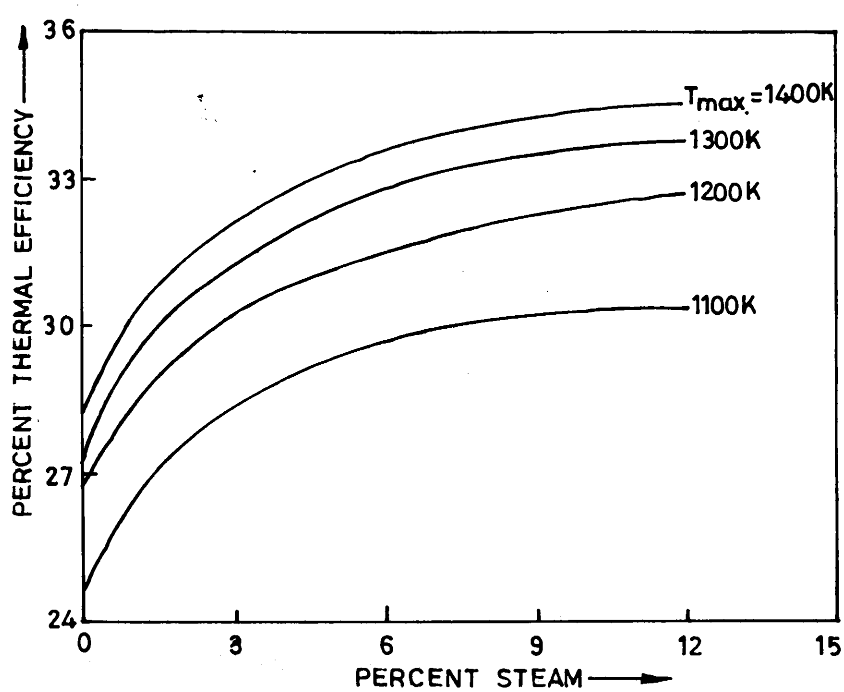


FIG. 6. EFFECT ON CYCLE EFFICIENCY FOR DIFFERENT TURBINE INLET TEMPERATURES.

HIGHLIGHTS ON THE ROLE OF ENERGY IN THE DEVELOPMENT OF ARAB COUNTRIES

Nasri K. Tarazi and Adnan I. O. Zaid

Technology and Applied Sciences Program
al-Quds Open University
P.O.Box 77 Umm Summaq
Amman, Jordan

ABSTRACT

The present energy situation in the Arab countries is assessed. Production and consumption of various resources are discussed, with particular emphasis on oil and gas. The potential application and contribution to the grass roots development of renewable energy resources is stressed.

The role of energy resources in the recent socio-economic changes in the Arab countries is discussed to conclude that they have gone through a process of growth and not development. The energy demand and supply for socio-economic development of the Arab world is then outlined, from which it can be found that for energy resources to be effective in development , a reversal of the past trends is needed.

The information and results presented herein highlight areas of importance for researchers to concentrate upon, and provide Arab energy policy designers with the input needed to formulate policies consistent with the development plans.

1. INTRODUCTION

Energy is not simply a physical quantity; it represents a complex system within any socio-economic development plan. Therefore, energy planning should be explicitly related to the overall economic and social planning. Otherwise, it would lose its purpose and validity in achieving well-defined developmental objectives [1].

Sound energy planning policies require intensive research and thorough database energy information. Such data and statistics in the Arab world are limited to those presented by European Economic Community (EEC), The Organization of Arab Petroleum Exporting Countries (OAPEC) and other non-specialized institutions. It is therefore expected that energy plans devised by any external agency could never be effective. The

integration of energy in Arab economy and its role in development still needs to be studied. The lack of strategic minerals in the Arab world, except for petroleum, natural gas and phosphate rock, makes this study pertinent.

Before analysing the role of energy in the development of Arab countries, one should survey their energy resources, the production, consumption, reserves and returns in order to assess the past trends and present situation.

2. ENERGY SITUATION IN THE ARAB COUNTRIES

2.1 Non-Renewable Sources of Energy.

Oil is still the most important of the non-renewable sources of energy in the Arab world. Natural gas ranks next to oil in importance. It can be seen from figure 1 that, taken together, proven oil and gas reserves amounted to 40.8% of the world's oil and gas reserves.

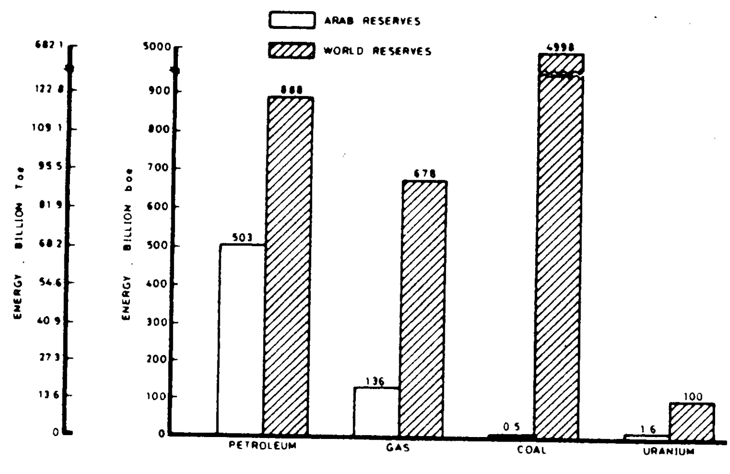


Fig.1. World and Arab Energy Reserves,1987.

This gives the impression that the Arab world is wealthy. However, this is only partially correct since the relative importance of oil and gas in the commercial energy consumed in the world is declining as is shown in figure 2, from 63.8% of the total commercial energy consumed globally in 1979 to 59.3% in 1987. It can also be seen from figure 2 that a drop in energy consumption occurred in 1979-1980 when the price of a barrel of oil was $34 US, and that a rise in consumption occurred when the price of the barrel dropped to $13.5-17.5 in 1986-1987. The rise in consumption has been slow in the period 1980-1984 despite the drop in prices in that period. This reflects the policy decisions of the importing countries to reduce their dependency on oil, and substitute it by other fuels.

The Arab energy consumption can be seen in figure 3. There is a great dependency on oil and gas, averaging around 95% of the total consumption, while other sources - mainly hydroelectricity - are of limited importance.

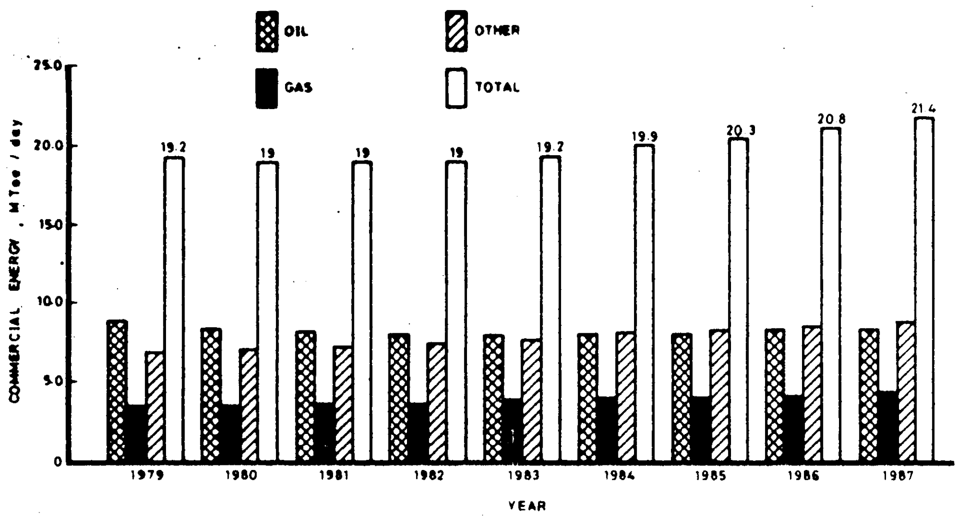


Fig.2. World Commercial Energy Consumption.

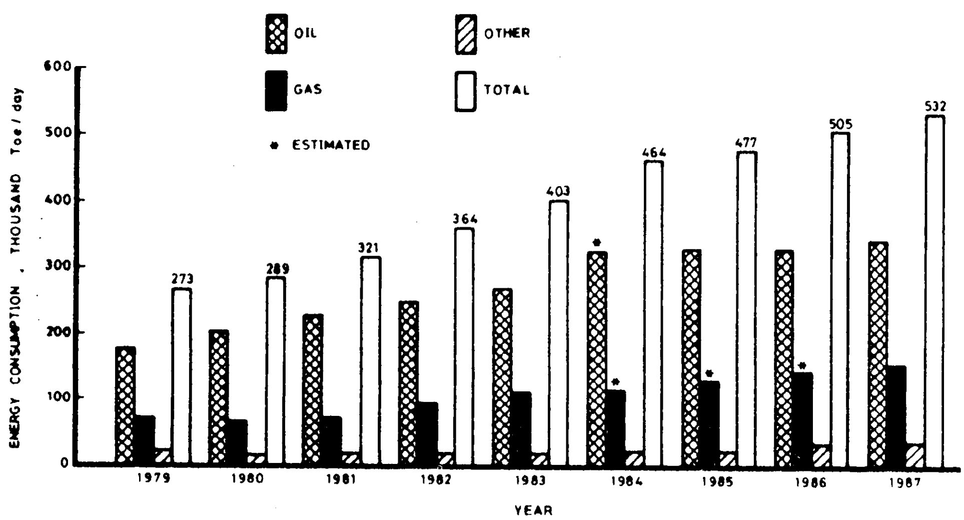


Fig.3 Arab Commercial Energy Consumption.

The rapid rise in production and local consumption of oil and gas caused the contribution of all other sources of energy to drop in relative, and sometimes in absolute terms. Those two feature when juxtaposed with the calls in the Arab world for the preparation for the post-oil era, indicate that very little has been done in that respect. Confirmation of this point can be extracted from figure 4 which shows the world and Arab production of crude oil, from which the declining importance of the Arab world as an oil producer is concluded. Preparing for the post-oil era means preserving an important status as a producer to accumulate enough returns for industrialization and development. Apart from the way in which the oil returns have usually been misspent, one can calculate that the Arab share of the oil market dropped from 36.0% in 1979 to 18.2% in 1985 and to 22.2% and 21.0% in 1986 and 1987, respectively. The relatively high price of oil up to 1986 caused the importing countries to conserve, research the alternatives and produce their own more-expensive-to-extract oil.

In order to remain dominant in the market, to push new producers out and to make alternatives not economically

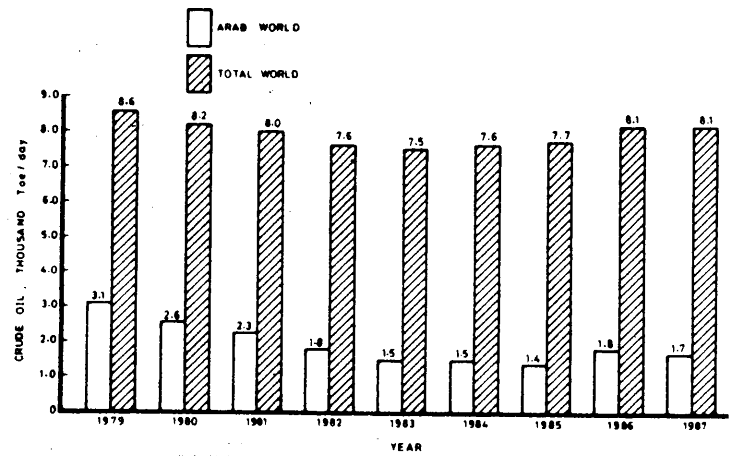


Fig.4. World and Arab Crude Oil Production.

feasible, some Arab countries increased their oil production in 1986. Note that the rise in world production between 1985 and 1986 was equal to the increase in the Arab production. This caused the Arab share of the market to increase in 1986, but the price dropped to an average of $13.5/barrel. The fact that the returns and the Arab share of market dropped again in 1987 is a proof that this policy has failed. This failure is best demonstrated by figure 5 which shows the Arab oil production and revenues. The drop in revenues up to 1985 reflects the drop in oil production form 1015MTo in 1980 to 519MTo in 1985, and the drop in oil prices from $30.5/barrel in 1980 to $26.7 in 1985. However, the drop in revenues in 1986 in due to the collapse of the prices despite the rise in production. The rapid rise in local consumption of oil and gas is a secondary cause for the drop in revenues.

To complete the picture, figure 6 shows the Arab energy production. It can be seen that production dropped in absolute terms up to 1985, and that the production of coal and hydroelectricity (not drawn) represent an insignificant ratio of energy production that declined in absolute terms too. The rise in production in 1986 has been explained and the slight drop in 1987 is an indication of stabilization at very low prices.

If a refining loss of 10% of the crude oil input is assumed, it can be calculated that the Arab share of the energy market dropped from 16.8% in 1980 to 9.6% in 1985, and was 10.4% in 1987. Local consumption of energy also rose from 9.5% of the energy produced in 1980, to 25% in 1985 and was 23.8% in 1987. It is true that there has been a large expansion in the energy sector in the Arab countries in the past years, but the increase in consumption, apart from being spent on growth reflects waste as well. For example, the per capita energy consumption for Qatar in 1980 was 8800 kgoe compared to 4606 kgoe for the leading industrialized countries. Furthermore, the Arab transport and industry sectors account for 28% and 50% of the energy consumption, the equivalent figures for the USA are 28% and 35% respectively. It can only be concluded that those figures are a sign of waste and not of development.

The following conclusions may be drawn:

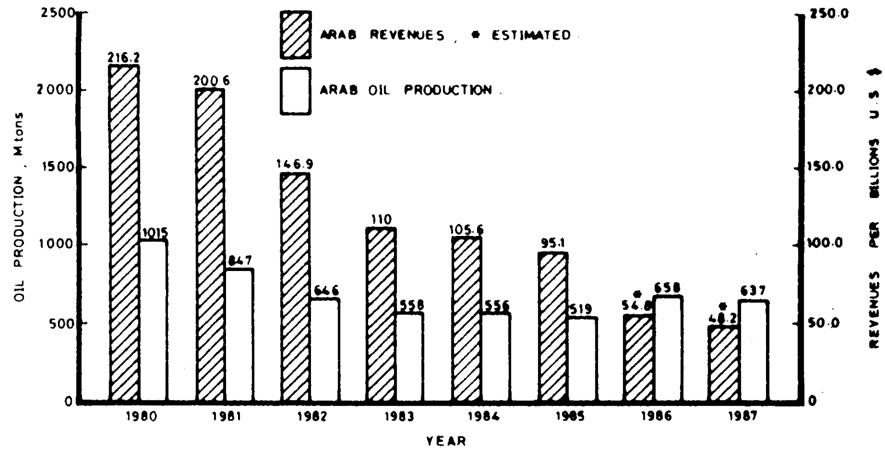


Fig.5. Arab Oil Production and Returns.

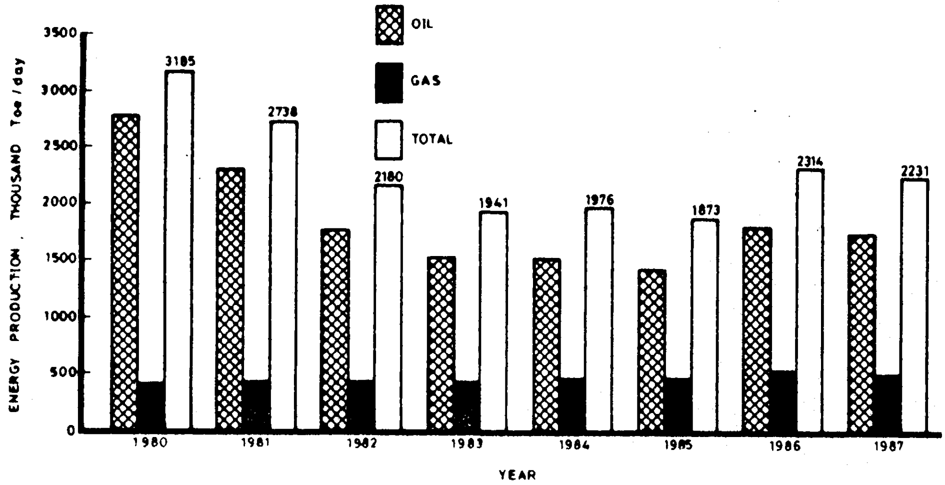


Fig.6. Commercial Arab Energy Production.

1. Energy policy in most Arab countries is not directed towards development and has so far failed to produce industrialization. Energy resources are treated as undepleatable sources of income.
2. Energy policy did not increase the returns or preserve a share of the market, and when it attempted to gain a larger share of the market, it only did so to the detriment of the revenues. In 1987 it could not even preserve that share which dropped together with the revenues.
3. Arab energy policy does not encourage conservation nor research and development while there is an urgent need for such measures.

2.2 Renewable Sources of Energy

The Arab world has abundant incomes of renewable energy resources. Table 1 gives an idea of the availability of these sources in MToe received annually [1]. It can be seen that solar energy constitutes 62.8% of the renewable energy received by the Arab world, and it in turn, exceeds six times the world's proven oil reserves [2].

One of the main objectives of researching the renewables besides the fact that they are appropriate and are of use especially in the rural areas, is to diversify the primary

1. Despite the substantial reserves of oil and gas, energy conservation should seriously be considered especially by those countries with little or no hydrocarbon reserves, because those reserves are depletable. Conservation in oil production should be considered, and gas should be used to substitute for oil or other sources of energy where possible to conserve oil and reduce the waste in gas. It is recommended that the level of production of non renewable resources be determined by the needs of the Arab development plans and not by the world consumption requirements.

2. Despite the limited utilization of solar and wind energy in some Arab countries, much remains to be done. Furthermore, exploring the feasibility of other renewable sources of energy such as biomass and geothermal energy should be carried out.

3. A central institution at the pan Arab level is needed to give a comprehensive outlook on energy and its role in socio-economic development. Its main functions should be to:

a) Establish an energy data base for the Arab world, which would form an essential prerequisite for energy planning.

b) Carry out unified research and studies on energy balances, energy forecasts by sector and by type, energy conservation and substitution. This would aid in the restructuring of the energy consuming sectors.

c) Lay down energy policies which incorporate energy planning within economic and social development.

Before all this can be successfully achieved, radical changes must occur in Arab countries, leading to changes in their relations with each other and with other countries. Similar changes in each country's priorities are necessary so that they would respond to their people's real needs and break away from dependency and consumption.

6. REFERENCES

[1] - KITTANI,M.A.,"The Role of Renewable Energy Sources in the Arab World", Solar Energy Workshop, Kuwait, March, 7-11, 1981.
[2] - KITTANI,M.A., "Solar Energy in the Arab World : New Perspective", Proceedings of the Second Arab Energy Conference", Doha, Qatar, March, 1982.
[3] - TAHA,T.A.,"Petroleum and Industrialization in the Arab World", Al-Mustaqbal Al-Arabi, The Centre for Arab Unity Studies, No.1, 1988. (Arabic).
[4] - OAPEC,"The Annual Report of the Secretary General", Nos. 8,11,12,13,14, 1982,1985,1986,1987,1988, Kuwait.(Arabic).
[5] - ARAB MONETARY FUND, The Unified Arab Economic Report, The Gulf House for Printing,Press and Publication, Sharjah, 1982,1984.(Arabic).

OPTIMAL POWER FLOW THROUGH AN UNIFIED CLASSICAL TECHNIQUE

J.Nanda V.P.Bapi Raju
Department of Electrical Engg.,
Indian Institute of Technology,
New Delhi-110016,India

S.C.Srivastava
Engineers India Ltd.,
New Delhi,India

F.M.Bara
Al-Fateh University
Tripoli,Libya

ABSTRACT

This paper presents an optimal power flow (OPF) model based on a classical technique. Solution of economic load dispatch problem through a set of coordination equations is well established. Surprisingly, such a set of coordination equations for the solution of optimal reactive power dispatch problem yet not established. A maiden attempt is therefore made to explore the feasibility of a set of coordination equations for the solution of optimal reactive power dispatch problem on lines similar to those for optimal real power dispatch problem. Subsequently the total problem of optimal power flow encompassing the twin problems of economic load dispatch and optimal reactive power dispatch is solved sequentially using a classical technique based on coordination equations. The proposed classical technique can effectively handle practical constraints on real and reactive power generations and transformer tap settings.

1. INTRODUCTION

An optimal power flow (OPF) provides a schedule of real and reactive power generations at a minimum generation cost and transmission loss along with a better voltage profile subject to system constraints. Several techniques based on classical, non-linear, linear, quadratic programming techniques etc. are in vogue for OPF [1] . H.H.Happ, in his review paper [2] concluded that classical method based on coordination equations is as good as any other rigorous method for economic dispatch problem. Although, this method is quite fast, it suffers from effective handling of all the system constraints. Surprisingly, such a classical technique based on a set of coordination equations has yet not been used for reactive power optimization. Hence, in this paper, a maiden attempt is made to explore a set of coordination equations for reactive power optimization. In order to solve the total problem of OPF at an enhanced computational efficiency, a set of new loss formulae are developed based on a perturbation technique [3] exploiting the sensitivity

Hence, only 2.5% of the Arab energy income was invested in the manufacturing industries.

Table 2. Breakdown in % of the GDP for some Arab countries,1980

Country Sector in %	Saudi Arabia	Qatar	UAE	Jordan	Egypt	Syria	Sudan	PDR	Somalia
Agriculture	3	0.9	1.1	6.2	17.8	20.2	35.3	11.4	49.5
Extraction	33	46.1	43.5	4.3	15.7	7.9	0.1	0.2	0.5
Manufacturing	7.5	6	8.7	15.7	14.1	11.7	7.7	14.5	6.1
Electricity, Gas & Water	--	0.5	1.9	2.1	0.7	0.2	2.1	1.5	0.9
Construction	15.5	7.2	10.6	9.3	4.7	6.5	4.9	11.8	3.6
Housing	3.7	5.3	6	---	1.9	---	5.2	2.5	---
Services	37.2	33.9	28.2	62.3	44.5	53.4	44.6	58	39.3
Total	100	100	100	100	100	100	100	100	100

The relationship between energy and production should be improved. For example, better use of appropriate energy should be made in agriculture. This would aid local development, provide jobs, stop migration to the cities and it does not alienate the population. Also, appropriate energy can be used in industry. For example, solar energy could save fuels or could be used for water desalination. Every region in the Arab world has its priorities and needs, and an appropriate energy can be used accordingly to a good technical and economic standard without losing the social dimension.

The ultimate goal of the previous discussion is to highlight the use of energy for development. Oil exporters should use their resources not only as sources of energy or income, but also as a driving force in the process of development for the whole of the Arab world.

National socio-economic development can only be achieved by activating the human and material resources in the society and their utilization under rational organization. Disunity within the Arab nation has resulted in the dispersion of human and material resources, despite the fact that the Arab countries complement each other in this respect. Therefore, it is an urgent necessity to unite the various capabilities of Arab countries in order to develop a heavy industry necessary for development. Because, so far, the Arab world has gone through a process of growth and not development.

4. ENERGY PLANNING IN THE ARAB WORLD

As mentioned earlier, in order to achieve well defined developmental objectives, the energy planning process should consider the variety of relations which exist between the energy system and the global economic and social system. Those objectives, sought by developing countries are discussed in detail in reference [1] as:

i) Related to the society:

This includes the overall social preference: consumption patterns, income distribution, employment, balance between

rural and urban areas, and sectoral policies. The links with the energy system will have to be identified, and the use of appropriate energy considered at every step in the production process until the end use.

ii) Related to the external world:
This includes the overall strategy, self reliance versus dependency, the relation with external partners, and hence, with the world market. The links with the energy system in this respect appear in the import and export of goods and services.

iii) Related to the natural environment:
This includes proper management of the various ecosystems, and the strategy of control and utilization of natural resources. The links with the energy system could take the form of pollution or desertification, and could appear when considering the balance between food crops and energy crops.

It is worth mentioning that these three sets of objectives are interrelated. For example, the choice of the industrialization policy has inevitable effects on the environment and the status in the world market.

After specifying and analysing these objectives for the Arab countries, the following information necessary for energy planning should be surveyed and identified:

a) The energy requirements to meet the socio-economic development plan.
b) The appropriate energy system(s) to meet those requirements.
c) The finance, man-power and technology needed to operate this system.
d) Different types of energy supplies (domestic and imported) available in each country.
e) The available energy options and substitutes for the energy supplies.

With such an amount of detailed data needed for integrated energy planning, energy planners must have a general view of the overall situation and a good sense of detail. Their success can be measured by the ease with which the economy obtains energy supplies, and by the efficiency with which it utilizes this energy. Such planning needs to be done on a pan-Arab level, because, taking into consideration agricultural and industrial policies, economic and demographic trends, social, environmental and economic constraints, would minimize bottlenecks and enhance development.

Despite the differences among Arab countries in term of energy resources, demand patterns, geography and political and social systems, they should work together on energy technology programs and common objectives in order to diversify the energy inputs and industrialize.

5. CONCLUSIONS

The following conclusions may be drawn:

energy resources, and to alleviate the pressure on hydrocarbon reserves in order to prolong their duration, and save them for the petrochemical industry.

Table 1 : Renewable energy sources in the Arab world for 1980 in MToe / year

Source	Income
Solar	2,322,000
Wind	1,376,000
Geothermal	1,892
Biomass	96.3
Hydro	3.7
Total	3,699,992

The viability of using renewables changes with time, and does not depend only on the availability, but also on the requirements, possible applications and technological progress. Therefore, when setting the energy plan for the Arab countries one should consider the energy network, the energy requirements, the resources, the technology both in the present and in the future. Furthermore, the concept of economic feasibility should be expanded to include the social effects of any project or source of energy.

Although renewable sources of energy are suitable and applicable to most Arab countries, their utilization is well below expectations. Arab countries use 10% of its total energy consumption from such sources, mainly fuel wood to the detriment of the ecosystem. Wind and solar energies have not been fully utilized despite the fact that they form more than 99.9% of the renewable energy income.

On the whole, the present Arab situation regarding renewable energy resources appears to be scant, fragmented and below the acceptable level. A lot of research and studies are required.

3. ENERGY AND DEVELOPMENT

Development can be defined as the process by which the society increases its output of goods and services for the greater satisfaction of people's needs. To reflect this increase in production, an increase in energy consumption or an increase in the efficiency of energy use must ensue. In other words "economic development means either more energy consumption or technological progress and societal changes of the kind which involves a reduction in energy use ,or a combination of all the above." [1]. The stability of the Arab dependency on oil and gas at almost 95% indicates that no structural changes have occured.

Energy consumption highly depends on the income level of each country as can be seen from figure 7 which was produced by classifying Arab countries into three groups:

a) High income group : Bahrain, Iraq, Kuwait, Libya, Oman,

Qatar, Saudi Arabia and the United Arab Emirates.
b) Medium income group : Algeria, Egypt, Jordan, Lebanon, Morocco, Syria and Tunisia
c) Low income group : Djiboti, Mauritania, North Yemen, Somalia, South Yemen and Sudan.

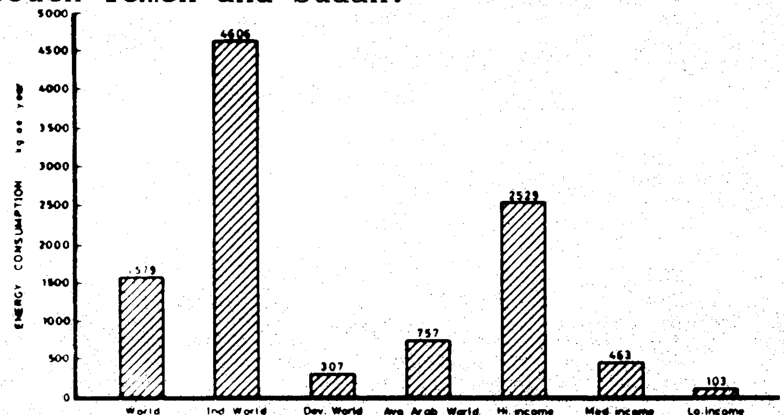


Fig.7. Per Capita Energy Consumption in 1980.

For the sake of comparison, the per capita energy consumption of the world, developing world and leading industrial countries are also shown. It can be seen that, while there is a great disparity among the Arab countries, the per capita consumption of the Arab world is only half that of the world. Comparing the figure of the industrially more advanced medium income group with the figure of the high income group, one can conclude that the use of energy is not a purely technological affair. To reinforce this conclusion table 2 can be considered. It gives the gross domestic product (GDP) by sector for some Arab countries. It can be seen that services form 28 - 62.3% of the GDP, while the high figures for extraction industry in Saudi Arabia, UAE and Qatar reflect the extraction of oil and gas and not an extraction industry as such.

Examination of the energy systems which have been built so far in most Arab countries to achieve development reveals that they suffer from unsatisfactory articulation with other parts of the production sector. The desire of most Arab countries (and especially the oil exporters) to achieve rapid progress, leads them to import vast amounts of goods and services by the energy sector, whilst neglecting the construction of local industries and training local personnel. An example of this can be seen in the turn-key jobs done to achieve rapid growth in the production of electricity. This was done at the expense of national industries which could have been established gradually alongside as a step in the direction of establishing an industrial base.

The medium income countries invested in manufacturing, and this took the form of import substitution. So, the policy was directed towards the local markets and not for exports. Apart from the almost worldwide failure of the policy of import substitution, the Arab countries invested only small amounts in this sector (21.3% of the total investment for the period 75-79, and 16.2% for the period 80-84). The total investment for the latter period equalled only 15.6% of the energy income.

properties of the Jacobian [J] already available at the end of a base case load flow (BLF). Evaluation of the new loss coefficients for the new loss formulae is quite fast and unlike the generalized transmission loss formulation which is quite involved and time consuming [4].

In essence, a new OPF algorithm based on classical coordination equations is proposed which solves the twin sub-problems of optimal real power generations (economic load dispatch-ELD) and optimal reactive power generations (OQG) sequentially till the desired convergence on minimum cost and minimum loss is achieved. The sub-problem of ELD considers minimization of total cost of generation whereas the sub-problem of OQG minimizes the total system active power loss. Constraints on real and reactive power generations and transformer tap settings have been duly considered.

An interesting feature of the proposed OPF method is its ability to handle effectively the constraints on on-load tap changing (OLTC). The effect of change in tap setting at a bus is simulated by injecting a fictitious reactive power at the bus where the voltage is controlled by an OLTC transformer. The amount of Q-injection needed is estimated during the solution of the OQG subproblem which helps in determining the new tap setting.

The proposed method is tested on two sample IEEE test systems and the results are compared with those obtained by linear programming approach.

2. NEW LOSS FORMULAE

Retaining the general feature of the expressions for losses as given in [4], a set of new loss formulae, one for real power loss(P_L) and the other for reactive power loss (Q_L) which are functions of only real and reactive power generations (PG^s and QG^s) are proposed as given below:

$$P_L=\left[\sum_{i=1}^{NG}(A_i PG_i)+\sum_{j=1}^{NQ}(B_j\ QG_j)\right]^2 \tag{1}$$

and

$$Q_L=\sum_{i=1}^{NG}(D_i\ PG_i^2)+\sum_{j=1}^{NQ}(E_j\ QG_j^2) \tag{2}$$

where A^s, B^s, D^s and E^s are new loss coefficients; NG=total number of buses having real power generations; NQ=total number of buses having reactive power sources which includes NG.

Evaluation of Loss Coefficients

At the end of a base load flow (Newton-Raphson power flow in cartesian form is used, $PG^{s(o)}$, $QG^{s(o)}$, $P^{s(o)}$, $Q^{s(o)}$, bus voltages and losses $P_L^{(o)}$ and $Q_L^{(o)}$ are known. Using these values, (1) and (2) are rewritten as

$$\sqrt{P_L^{(o)}}=(A_1\ PG_1^{(o)}+\ldots+A_{NG}PG_{NG}^{(o)})+(B_1QG_1^{(o)}+\ldots+B_{NQ}QG_{NQ}^{(o)}) \tag{3}$$

and

$$Q_L^{(o)}=(D_1\ PG_1^{(o)2}+\ldots+D_{NG}PG_{NG}^{(o)2})+(E_1QG_1^{(o)2}+\ldots+E_{NQ}QG_{NQ}^{(o)2}) \tag{4}$$

(NG+NQ) pairs of equations similar to (3) and (4) are required to evaluate all the loss coefficients. Since, base quantities are known, (NG+NQ-1) pairs of equations are needed to be generated. This is achieved by using the perturbation technique [3] wherein the changes in slack bus powers ΔP_1 and ΔQ_1 (Bus-1 as slack) and also losses P_L and Q_L are computed by exploiting the sensitivity properties of the Jacobian [J] available at the end of a base load flow (BLF) by perturbing a small amount each real power ΔP_r and each reactive power ΔQ_r at a source bus-r one at a time except at the slack bus, keeping all other bus powers fixed. If real power is perturbed by P_r at bus-r, the following changes are noted:

$$PG_1^{(1)} = PG_1^{(o)} + \Delta P_1 \; ; \; QG_1^{(1)} = QG_1^{(o)} + \Delta Q_1 ; \; PG_r^{(1)} = PG_r^{(o)} + \Delta P_r ;$$

$$P_L^{(1)} = P_L^{(o)} + (\Delta P_1 + \Delta P_r) ; \; Q_L^{(1)} = Q_L^{(o)} + \Delta Q_1 : \tag{5}$$

Similarly, if reactive power is perturbed by ΔQ_r at bus-r, the following changes are noted:

$$PG_1^{(1)} = PG_1^{(o)} + \Delta P_1 ; \quad QG_1^{(1)} = QG_1^{(o)} + \Delta Q_1 ; \quad QG_r^{(1)} = QG_r^{(o)} + \Delta Q_r ;$$

$$P_L^{(1)} = P_L^{(o)} + \Delta P_1 \text{ and } Q_L^{(1)} = Q_L^{(o)} + \Delta Q_1 + \Delta Q_r \tag{6}$$

In equations (5) and (6), the only unknowns are ΔP_1 and ΔQ_1. These are computed as follows:

$$\Delta P_1 = \left[\frac{\partial P_1}{\partial e_2} \cdots \frac{\partial P_1}{\partial e_N} \; \vdots \; \frac{\partial P_1}{\partial f_2} \cdots \frac{\partial P_1}{\partial f_N} \right] [\Delta V] \tag{7}$$

and

$$\Delta Q_1 = \left[\frac{\partial Q_1}{\partial e_2} \cdots \frac{\partial Q_1}{\partial e_N} \; \vdots \; \frac{\partial Q_1}{\partial f_2} \cdots \frac{\partial Q_1}{\partial f_N} \right] [\Delta V] \tag{8}$$

$$\text{where } [\Delta V] = [\Delta e_2 \ldots \Delta e_N : \; \Delta f_2 \ldots \Delta f_N]^T \tag{9}$$

e^s and f^s are the real and imaginary parts of the voltages.

$$\Delta V \text{ can be expressed as } [\Delta V] = [J]^{-1} [\Delta S] \tag{10}$$

where $[\Delta S] = [0 \ldots \Delta P_r \ldots 0 : 0 \ldots 0]^T$ for real power perturbation at bus-r and $[\Delta S] = [0 \ldots 0 : 0 \ldots \Delta Q_r \ldots 0]^T$ for reactive power perturbation at bus-r. Since, $[J]^{-1}$ is already available at the end of a BLF, finding the voltages for each kind of perturbation is quite trivial as only one non-zero entry is present in ΔS. In this manner, all the (NG+NQ-1) pairs of equations similar to (3) and (4) are generated and alongwith the base equations (3) and (4), All the loss coefficients can be computed by solving the (NG+NQ) pairs of equations.

3. COORDINATION EQUATIONS FOR ELD

The coordination equations for optimal real power dispatch 6 are well known and are given below:

$$\frac{\partial F_1}{\partial PG_i} + \lambda_P \frac{\partial P_L}{\partial PG_i} = \lambda_P ; \quad i=1 \text{ to NG} \tag{11}$$

where F_1 is the total cost of generation. The cost characteristics for each generator is taken as $f_i = 0.5 a_i \, PG_i^2 + b_i \, PG_i + c_i$ where a_i, b_i and c_i are constants. The solution of (11) gives

Table-I: Optimum cost and loss figures without OLTC

System	Type of loss formulae used	Case Study-1		Case Study-2		Case Study-2
		Total cost of generation in \$/Hr.	Total system losses P_L (MW)	Total cost of generation in \$/Hr.	Total system losses P_L (MW)	CPU time in seconds
1	2	3	4	5	6	7
IEEE 14-Bus	Rigorous [4]	1136.105	9.205	1135.991	9.161	10.76
	Proposed	1138.820	10.084	1138.553	10.029	5.365
IEEE 30-Bus	Rigorous [4]	1245.991	10.620	1245.786	10.532	54.607
	Proposed	1246.705	10.126	1246.680	10.273	31.736
IEEE 14-bus	Base case	1156.402	11.703			
IEEE 30-Bus	Base case	1288.102	15.341			

Table-II: Optimum cost and loss figures and CPU time (with OLTC)

System	Method of OPF	Total cost of generation in \$/Hr.	Total system loss P_L (MW)	Time in seconds
1	2	3	4	5
IEEE 14-Bus	Proposed (case study 2)	1138.573	10.035	7.245
	LP Based [5]	1133.521	8.844	29.879
IEEE 30-Bus	Proposed (Case Study 2)	1246.692	10.271	68.332
	LP Based [5]	1251.304	11.165	290.581

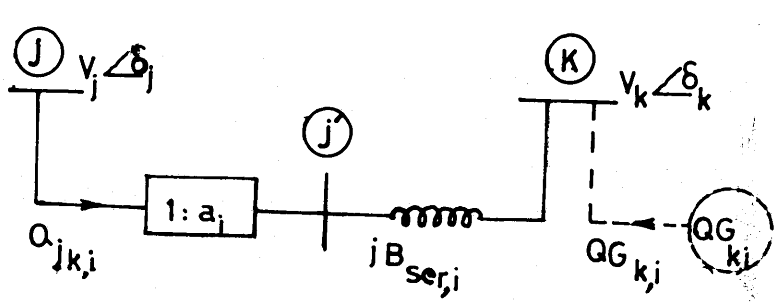


Fig.1: Representation of an OLTC Transformer

better to those of the LP model, whereas for the 14-bus system,, the LP model gives somewhat better results. However, the CPU time for OPF solution based on the classical technique is much less as compared to the CPU time for the OPF solution based on the LP model.

In general, studies clearly reveal that classical model for OPF solution should be preferred to LP based model for real time applications:

10. CONCLUSIONS

1. A maiden attempt is made to solve OPF problem using a classical technique based on coordination equations alongwith a set of new loss formulae.
2. It is demonstrated for the first time that the reactive powers can also be optimized from a set of coordination equations similar to the well-known coordination equations for optimal real power dispatch. Results obtained by new loss formulae are in close agreement with those obtained through generalized loss formulae. Moreover, the computation of loss coefficients in the new loss formulae is quite efficient and has a distinct edge over the generalized loss formulation which is quite involved and time consuming.
3. An attempt is made for the first time to incorporate the OLTC constraints in the classical model for OPF.
4. The results obtained by the proposed classical method are in close agreement to those obtained by a more rigorous LP based method indicating the potential of the proposed method for practical application.
5. The proposed method is easy to program and requires significantly less memory and computation time as compared to the LP based model and thus should appeal to the utilities for real time applications.

REFERENCES

1 IEEE VAR management group report, "Bibliography on reactive power and voltage control",IEEE Trans.on PAS, Vol PWRS-2, No.2, May 1987,PP.361-370.

2 H.H.Happ, "Optimal power dispatch - A Comprehensive Survey", IEEE Trans., Vol PAS-96, May/June 1977, pp841-854.

3 J.Nanda and P.R.Bijwe, "A novel approach for generation of transmission loss formulae coefficients", IEEE-PES Summer Meeting, 1977, Paper No. A-77-599-4

4 Elgerd Olle, I.,"Electric Energy Systems Theory - An Introduction", McGraw-Hill Inc., New York 1971.

5 G.C.Contaxis, C.Delkis and G.Korres, "Decoupled Optimal Flow using Linear or Quadratic Programming",IEEE.Trans., Vol. PWRS-1, No.2 May 1986, pp 1- 7.

generations PG_i (i=1 to NG) are computed in the subproblem of ELD by solving a set of coordination equations in (11) while satisfying the inequality constraints imposed on PGs and the equality constant (active power balance equation). Similarly, the optimal reactive power generations QG_i (i=1 to NQ) are computed in the subproblem of OQG while satisfying the inequality constraints on QGs and the equality constraint (reactive power balance equation) by solving the coordination equations given by (14). Both these subproblems ELD and OQG are sequentially solved till the desired convergence on minimum cost and minimum loss is achieved.

8. COMPUTATIONAL STEPS

1. Read system data, generator cost characteristics, limits on active and reactive powers and OLTC transformers.
2. Use equal incremental cost criteria to get a new set of real power generations. Specifying these new real power genrations except at Slack, Perform a BLF. Compute cost of generation losses P_L and Q_L.
3. Compute loss coefficients A^s, B^s, D^s and E^s.
4. Sub-problem OPG:

   i) Find initial value of λ_P from (21)

   ii) Using the value of λ_P, solve the coordination equations (11) to find PGs while satisfying the inequality constraints using Gauss-Seidel technique.

   Let $P_{eq} = \sum_{i=1}^{NG} (PG_i) - (P_L + P_D)$ where P_L is computed from (1)

   If $|P_{eq}| \leq \varepsilon_1$, go to sub-step(vii); If P_{eq} is +ve, go to sub-step(iii); If P_{eq} is -ve, go to sub-step(iv)

   iii) Store λ_P as λ_P^+ and decrement λ_P by a known quantity $\Delta\lambda_P$ and go to step (v)

   iv) Store λ_P as λ_P^- and increment λ_P by $\Delta\lambda_P$.

   v) If both λ_P^+ and λ_P^- are obtained at which the function values P_{eq}^s change sign, go to step(vi). Otherwise, go to substep (ii).

   vi) Use λ_P^+ and λ_P^- as upper and lower bounds of λ_P and solve for P_G^s such that $|P_{eq}| \leq \varepsilon_1$ using the Regula-Falsi technique 7 . This technique ensures less number of iterations to obtain the optimal PGs and optimal λ_P.

   vii) Update PG^s.
5. Sub-problem OQG.

   i) Find initial value of λ_Q from (22)

   ii) Using the value of λ_Q, solve the coordination equations (14) to find QGs while satisfying the inequality constraints using Gauss-Seidel technique.

   Let $Q_{eq} = (\sum_{i=1}^{NQ} QG_i) - (Q_L + Q_D)$ where Q_L is computed from (2)

   If $|Q_{eq}| \leq \varepsilon_2$, Go to sub-step (vii);

If Q_{eq} is +ve, go to sub-step (iii)
If Q_{eq} is -ve, go to sub-step (iv)

iii) Store λ_Q as $\lambda_Q^{\pm}$ and decrement λ_Q by $\Delta\lambda_Q$ and go to sub-step (v)

iv) Store λ_Q as $\bar{\lambda}_Q$ and increment λ_Q by $\Delta\lambda_Q$.

v) If both $\overset{+}{\lambda}_Q$ and $\lambda\bar{\lambda}_Q$ are obtained at which function values Q^s_{eq} change sign, go to sub-step (vi). Otherwise, go to sub-step (ii)

vi) Use $\overset{+}{\lambda}_Q$ and $\bar{\lambda}_P$ as upper and lower bounds of λ_Q and solve for QG^s such that $|Q_{eq}| \leq \varepsilon_2$ using the Regula-Falsi technique.

vii) Update QG^s.

6. Run a load flow treating the buses as P-Q type. Compute the cost of generation and system loss. If both cost and loss P_L are converged, an OPF solution is reached. Otherwise increment the iteration count and go to step 3. This process is repeated till the desired convergence criteria are satisfied.

9. SYSTEM STUDIES

The proposed classical technique based on coordination equations for optimal power flow solution is tested on IEEE-14 bus and IEEE-30 bus systems. Two case studies are performed. In case study-1, constraints on PG^s and QG^s are only considered and changes in OLTC tap settings ignored. Loss formulae by both the rigorous and the proposed approaches are worked out and used in the OPF model in order to compare their performances. Moreover, the loss formulae coefficients are updated for each iteration of the OPF by both the approaches.

In case study-2, the constraints are same as in case study-1 but the loss formulae coefficients by both the approaches are kept constant as evaluated from the base case load flow and the OPF results are obtained and compared with those of case study-1 in order to establish whether such loss coefficients can be permissible to be kept constant. The results for the two case studies are given in Table-I.

Results clearly reveal that the cost and loss figures for both the systems tested are more or less in close agreement, thereby establishing the validness of the proposed new loss formulation. Moreover, the solution time obtained by using the proposed loss formulation is much faster than using the rigorous loss formulation.

Investiations are carried out by incorporating the constraints on the OLTC tap settings in to the model for case study-2 using the proposed loss formulation and maintaining the loss coefficients constant throughout the iteration process. Optimal power flow results for this situation using the classical technique are compared with the OPF results obtained through a more rigorous LP model as used by Contaxis et. al [5] . Results are given in Table-II. The results reveal that the cost and loss figures obtained by both classical and LP based models are comparable. Infact, in 30-bus system cost and loss figures obtained by the classical model are

the optimal real power generations P_G^s and are dependent on the selection of λ_P. The constraints imposed are

$$\sum_{i=1}^{NG} (PG_i)-P_L-P_D=0 \text{ and } PG_i^{min} \leq PG_i \leq PG_i^{max}; i=1 \text{ to } NG$$

4. COORDINATION EQUATIONS FOR OQG:

It is well-known that transmission loss is predominantly affected by the voltage profile of the system. Because of close coupling between voltage magnitudes and reactive powers, loss minimization is essentially a reactive power optimization problem. Mathematically, the problem can be stated as:

$$\text{Minimize } P_L \;; \quad \text{s.t} \quad \sum_{j=1}^{NQ} (QG_j)- Q_L -Q_D =0 \qquad (12)$$

and

$$QG_j^{min} \leq QG_j \leq QG_j^{max} \quad ; \; j=1 \text{ to } NQ.$$ NQ consists of buses having OLTC either at a generator bus or at any other bus. Using the method of Lagrangian multiplier, the new objective function can be defined as

$$F= P_L- \lambda_Q \sum_{j=1}^{NQ} (QG_j) - Q_L - Q_D \qquad (13)$$

For minimum of F, the necessary conditions $\partial F/\partial QG_j=0$; j=1 to NQ and $\partial F/\partial \lambda_Q=0$ are to be satisfied. Invoking these conditions for $\partial F/\partial QG_j=0$, it can be shown that

$$\frac{\partial P_L}{\partial QG_j}\left(\frac{1}{1-\frac{\partial Q_L}{\partial QG_j}}\right) = \lambda_Q \quad \text{or} \quad \frac{\partial P_L}{\partial QG_j}+\lambda_Q \frac{\partial Q_L}{\partial QG_j}= \lambda_Q; \; j=1 \text{ to } NQ \qquad (14)$$

and $\partial F/\partial \lambda_Q=0 = \sum_{j=1}^{NQ} (QG_j)-Q_L-Q_D$ is the reactive power balance equation and is same as (12). $\partial P_L/\partial QG_j$ is incremental transmission loss at jth reactive source in MW per MVAR;
$1/ 1- \frac{\partial Q_L}{\partial QG_j}$ can be considered as penalty factor (PFR) for the jth bus.

The set of equations (14) are referred to as exact coordination equations for optimal reactive power dispatch and suggests that the minimum loss is achieved when the incremental changes in transmission losses to incremental changes in net reactive power multiplied by the corresponding PFR is same at all reactive bus sources. The solution of these equations gives the optimum reactive powers QG^s and depends on the selection of λ_Q (The Lagrangian multiplier).

5. REPRESENTATION OF ON LOAD TAP CHANGING (OLTC):

The change in transformer tap settings mainly affects the voltage level which in turn affects the reactive power injections, and hence the consideration of tap settings in the model for OQG is relevant. The main concept lies in the fact that if the additional reactive power injection needed to maintain the voltage of a bus being controlled by OLTC is known, desired tap setting value can be back computed from a matehamtical

expression relating to tap setting and reactive power. In this context, a fictitious Q- source is being assumed at the bus whose voltage is being controlled by an OLTC. Each fictitious Q- source represents the effect of change in tap setting of one transformer.

Referring to Fig.1, a fictitious Q-source $QG_{k,i}$ (ith transformer) is represented at bus-k whose voltage is controlled by OLTC. The fictitious reactive power is provided in the form of a change in the reactive power flow from bus -j to bus-k due to change in tap setting from say $a_i^{(o)}$ to a new value $a_i^{(n)}$ and is shown as

$$QG_{k,i} = Q_{jk}^{(n)} - Q_{jk}^{(o)} \tag{15}$$

Assuming no changes in voltage angles,

$$Q_{j,k}^{(o)} = -\,\mathrm{Imag}(V_k^* \, I_{jk}) = -\,\mathrm{Imag}\left[V_k \angle -\delta_K (V_k \angle \delta_k - a_i^{(o)} \, V_j \angle \delta_j) \, j \, B_{ser,i}\right] \tag{16}$$

$$\therefore \quad Q_{j,k}^{(o)} = a_i^{(o)} \, V_j \, V_k \, B_{ser,i} \cos(\delta_j - \delta_k) - V_k^2 \, B_{ser,i} \tag{17}$$

and similarly

$$Q_{j,k}^{(n)} = a_i^{(n)} \, V_j V_k \, B_{ser,i} \cos(\delta_j - \delta_k) - V_k^2 \, B_{ser,i} \tag{18}$$

Substituting (17) and (18) in (15),

$$QG_{k,i} = V_j \, V_k (a_i^{(n)} - a_i^{(o)}) B_{ser,i} \cos(\delta_j - \delta_k) \tag{19}$$

using equation (19), the limits on reactive power can easily be computed reflecting the actual limits on OLTC transformer. In (19), $QG_{k,i}$ is estimated while solving the OQG subproblem. The voltage magnitudes V_j and V_k can be estimated using the following relations

$$\begin{bmatrix} \Delta QG \\ \Delta Q_L = 0.0 \end{bmatrix} = \begin{bmatrix} S_{GG} & S_{GL} \\ S_{LG} & S_{LL} \end{bmatrix} \begin{bmatrix} \Delta V_G \\ \Delta V_L \end{bmatrix}$$

where the suffixes G and L stand for source buses inclusive of those having fictitious Q-sources and load buses respectively.

The entries of the various submatrices are the partial derivatives $[\partial Q/\partial V]$. $[\Delta Q_L] = [0]$ since the changes in loads are assumed to be zero during the study of OPF problem. Having known $QG_{k,i}$, V_j and V_k, the required new tap setting can be computed using equation (19).

6. INITIAL ESTIMATES OF LAGRANGIAN MULTIPLIERS: λ_P and λ_Q

In order to solve the subproblems ELD and OQG, the starting values of λ_P and λ_Q are chosen as

$$\lambda_P = \left(\sum_{r=1}^{NG} \lambda_{Pr}\right)/NG \quad , \text{ and } \quad \lambda_Q = \left(\sum_{r=1}^{NQ} \lambda_{Qr}\right)/NQ \tag{21)\&(22}$$

where λ_{Pr} is computed using eqn. (11) knowing the base load flow values.
Similarly λ_{Qr} is computed using eqn. (14).

7. OPF ALGORITHM

Starting from a base load flow, the optimal real power

6 L.K. Kirchmayer, "Economic operation of power systems", Wiley Eastern Limited.

7 Steven C.Chapra, Raymond P.Canale, "Numerical Methods for Engineers with Personal Computer Applications",McGraw-Hill Book Company.

Thermal Conversion (Visbreaking) of Heavy Iraqi Residue

Al-Soufi, H.H., Savaya, Z.F., Mohammed, H.K. and Al-Azawi, I.A

Council of Scientific Research, Petroleum Research Centre,
Jadiriyah - Baghdad, P.O. Box 10039, Iraq

ABSTRACT

A heavy Iraqi residue was thermally cracked using soaker visbreaking process at temperature range 435 to 480 ^{o}C and residence time range 43 - 109 sec in coil and 151-379 sec in the soaker. The pressure was kept constant at 7 bar.

Visbroken products were characterized, evaluated and fractioned to light, middle and heavy cuts in which their characters were reported.

The stability of visbroken products has been studied and compared with that of the original feedstock. Furthermore, activation energy was calculated and related with the severity of the process.

The results obtained show that the studied conditions were not severe and could be applied to get any conversion required depending on the uses of the products.

INTRODUCTION

Visbreaking is one of the most interest thermal cracking processes that offered a means for increasing the fluidity of of the resid and the yield of light products from crude oil. This process can be used to convert a necessary conditions for success depending on the chemical nature of the feedstock and the cracking conditions[1,2]. The basic technology of visbreaking has been adequently covered by a number of publications[3,4].

Visbreaking yields are crude dependent. The amount of cracking is limited by coking in the furnace coil and by potential instability of the bottoms product. Because the high molecular weight material usually associated with high resid asphaltene levels exists as a suspension in crude, a large reduction of the resid volume can cause the asphaltenic material to precipitate. For this reason, visbreaker operation at excessively high severity can lead to fuel oil product instability before furnace coking becomes limited.

The present article describes the effect of the feedstock conversion level on the yield products and quality of a heavy iraqi residue at different conditions.

EXPERIMENTAL

Long residue (350 ^{o}C) of 20 API containing high asphaltenes, 9.5 wt% , was used. It was obtained by atmospheric and vacuum distillation of relatively a heavy Iraqi crude oil. Visbreaking reaction was performed in a

continuous visbreaker unit of 2L/h feed in a tube reactor with soaker which is described in a previous work[5].

Visbroken products, after throttling down the pressure and cooling, were seperated and analyzed to determine whether their quality indexes conform to those specified in the standard of residual fuel oil. Moreover, these products were distilled taking off the cuts : up to 150 °C, 150-350 °C and 350-500 °C which were evaluated according to IP and ASTM standard methods.

RESULTS AND DISCUSSION

In the visbreaking of resid, the same as in any other form of thermal cracking, a necessary condition for success is long term operation of the reaction tube coil with an acceptable degree of conversion. this depends on the chemical nature of the feedstock and the severity of the cracking conditions.

visbreaking of a heavy Iraqi residue was carried out over the temperature range 435 to 480 °C and residence time range was 43 to 109 sec in the coil and 151 to 379 sec in the soaker. The pressure was kept constant at 7 bar for all experiments.

Table 1 shows the physico-chemical properties of the studied long residue at different visbroken temperatures namely, 435, 450, 465 and 480 °C. The residence time selected was 67 sec in the coil and 292 sec in the soaker taking into consideration the stability of visbroken products which is discussed later.

It is clear that as the temperature is increased, there is an increase only in the percentage of conradson carbon residue while a decrease is shown in all other index values. This is an indication for the increase in the conversion of the fuel. The conversion was defined as the total yield of distillates (up to 350 ^{o}C) obtained after visbreaking of the long residue.

Visbreaking temperature affects not only the rate but also the characters of the reactions in resid cracking. Table 2 shows the yield and characteristics of the products formed from visbreaking of the residue at the conditions mentioned above. The conversion was raised from 2.8 to 13.7 by weight corresponding to temperature range 435 to 480 ^{o}C

By examining the results obtained in visbreaking of the studied residue, it is clear that the conversion way of the feedstock influences the yield of the products. Fiqure 1 shows the relation between the conversion and the yield of the products.

As the conversion is increased, the yield of the middle distillate (150-350 ^{o}C) increased which is the most important in terms of lowering the viscosity of the fuel oil. The yield of gas and 350-500 ^{o}C cut increased too whereas the yield of the corresponding residues decreased. The light cut (up to 150 ^{o}C), was only obtained at visbreaking temperature of 480 ^{o}C in very small quantity (0.7 wt.%).

It is known that residence time has direct effect on the cracking rate , therefore, visbreaking was performed at

different residence times ranged 43 to 109 sec in the coil and 151 to 379 sec in the soaker. Visbreaking temperature chosen was 465 ^{o}C which was considered as the limited temperature for an acceptable stability. Figure 2 shows the change in the visbroken product characters at different temperatures and residence times.

The great contribution of the visbreaker to the refinery is not in reducing the total volume of resid, but rather in reducing the cutterstock required to meet viscosity specifications. The major concerns when selecting the operation conditions and conversion ratio for a visbreaker is cracking and resulting fuel oil stability.

The stability test was carried out for visbroken products to ckeck on the severity of the applied conditions. It was studiéd as a function of n- heptane insolubles[6]. The severity of the process was defined by the flocculation ratio (FR) of the visbreaker residue.

By comparing the results obtained with the original feedstock stability, no significant decrease in the stability of the studied residue was shown when visbreaking temperature was increased. The flocculation ratio range was between 40-50% at temperature range 435-480 ^{o}C while that of the feed was 32%. Furtheremore, activation energy was calculated from first order equation depending on the conversion factor of the feed and it was only 23.7 Kcal / mole.

Since the condensation reactions causing asphaltenes and coke formation have an activation energy ranging from 60 - 90 Kcal / mole[1] and that calculated in the present

work was only 23.7 Kcal/ mole, so this will support the suggestion that the studied conditions were not severe and that secondary reactions, which decrease the stability, were limited.

Therefore, any of the studied conditions could be selected for maximum conversion regarding the uses of the required products. The above results also show that most properties of the obtained middle distillate are acceptable when compared with the commercial specifications except some propertied which could be improved by hydrotreating.

REFERENCES

1. Hus, M. : Oil & Gas Journal, Apr. 13, 109, 1981.
2. Rhoe, A. and Blignieres, C.de. : Hydrocarbon Processing, 58, 131, 1979.
3. Singh, V.D. : Science & Technology, 19, 1986.
4. Akbar, M. and Geelen, H. : Hydrocarbon Processing, May 81, 1981.
5. Al-Soufi, H.H., Shanshool, J., Savaya, Z.F., Mohammed, H.K. and Al-Azawi, I. : In press.
6. Giavarini, C. : Thermal Processes, 60, 401, 1981.

Table -1-

Physico - chemical properties of a heavy Iraqi long Residue and its visbroken products.

Specifications	Feed 350 °C+	Reaction temperature (°C) 435	450	465	480
Specific Gravity 15/15 °C	1.0190	1.0132	1.0102	1.0053	0.9995
Flash Point (Penesky), °C	199	75	61.5	42.5	27.5
Total sulphur, wt.%	6.68	6.68	6.64	6.61	6.59
Conardson Carbon, wt.%	14.76	15.61	16.3	16.59	17.22
Pour point, °C	33	16	12	6.4	-2
Viscosity cSt at:					
50 °C	12362	4123	2470	1374	709
100 °C	384	174	134	91	76
Flocculation ratio wt.%	32	40	43	46	50

Table -2-

Physico-Chemical Properties of various fraction at different reaction temperatures. Residence time = 67 sec in the coil and 292 sec in the soaker.

Products properties	Visbreaking temperature (°C)			
	435	450	465	480
150 - 350 °C fraction				
Specific gravity, 15/15 °C	0.9105	0.8826	0.8715	0.8708
Viscosity, cSt at 50 °C	2.73	2.60	2.49	2.32
Sulphur, wt%	3.84	3.74	3.55	3.17
Aniline point, °C	40	43	43	45
Yield, wt%	2.50	5.08	8.60	11.80
350 - 500 °C fraction				
Specific gravity, 15/15 °C	0.9440	0.9387	0.9325	0.9265
Viscosity, cSt at 50 °C	25.27	24.90	24.57	18.92
sulphur, wt.%	4.64	4.80	4.80	4.75
Pour point, °C	19	15	12	7
Yield, wt%	22.00	25.16	28.62	31.44

continued:

continued:

Product Properties	435	450	465	480
Residue above 150 °C				
Specific gravity, 15/15 °C	-	-	1.0128	1.0050
Flash point, °C, C.O.C.	-	-	33	56
Sulphur, wt.%	-	-	6.6	6.4
Conradson carbon, wt.%	-	-	16.4	16.7
Pour point °C	-	-	8	-2
Viscosity, cSt at:				
50 °C	-	-	784	1481
100 °C	-	-	86	95
Residue above 350 °C				
Specific gravity, 15/15 °C	1.0240	1.0295	1.0407	1.0446
Flash point, °C C.O.C.	260	252	245	236
Sulphur, wt.%	6.53	6.57	6.68	6.81
Conradson carbon wt.%	16.7	17.9	19.9	21.2
Pour point °C	22	24	25	27
Viscosity at :				
50 °C	9192	9260	12260	14370
100 °C	-	299	344	362
Residue above 500 °C				
Specific gravity 15/15 °C	1.0722	1.0740	1.0764	1.1668
Sulphur wt.%	6.9	7.1	5.4	7.3
Conradson carbon wt.%	25.2	26.0	27.3	28.0

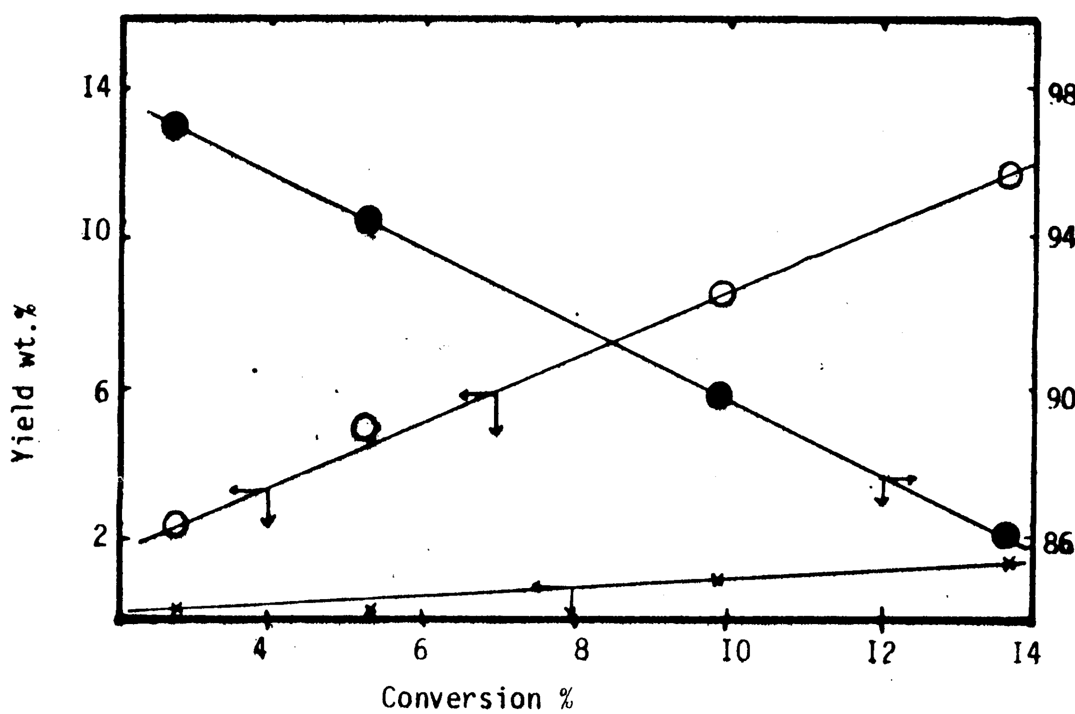


Figure I. Yield of distillates and residue as function of conversion. Operating conditions :- Temp. = 435 - 480^{0}C, residence time = 67 sec.

x- gas, O 150 - 350^{0}C, ● - 350^{0}C$^+$

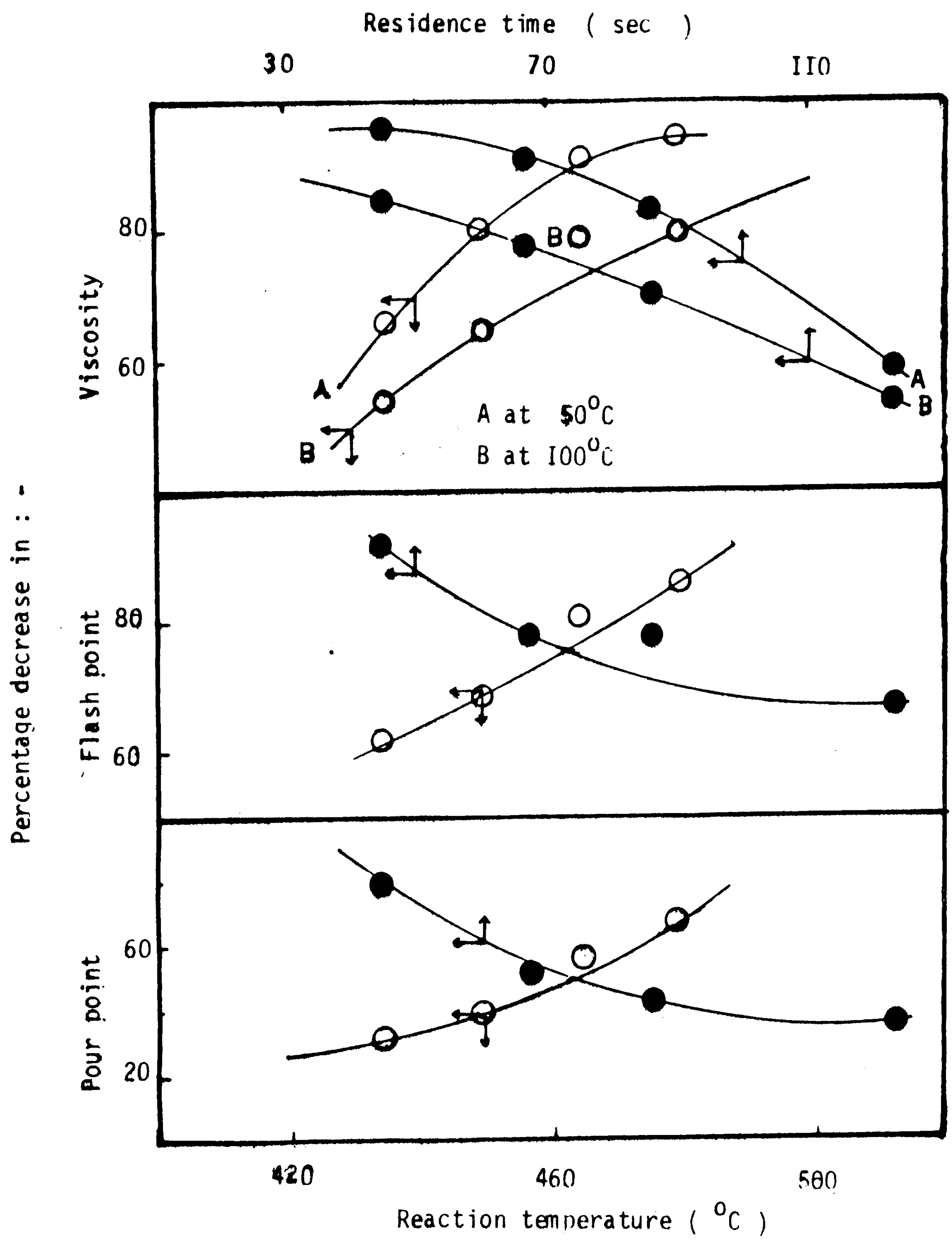


Figure 2. The effect of operating conditions on the physico - chemical properties of visbroken products. ○ Temperature, ● Residence time

PERFORMANCE ANALYSIS OF INTERNAL COMBUSTION ENGINE BY BUBBLING COMBUSTION AIR THROUGH WATER

J. Sarangan, Mrs. S.K. Pandey, T.S. Rajan

Regional Engineering College,
Tiruchirapalli-620015.
INDIA.

ABSTRACT

Laboratory experiments were conducted on a 'HONDA' Generator to study the effects of moisture on the performance of the I.C.engine by bubbling the combustion air through distilled water and then introducing it into the combustion chamber. Measured quantities of fuel were sent to the engine generator and the time taken for combustion of specific quantity of fuel was noted. The generator was loaded in steps with the help of a lamp load and output power was noted by means of a precision grade wattmeter.

Experimental results were compared for three types of air input to the engine generator i.e. atmospheric air, saturated air at room temperature and saturated air at temperatures upto 52 °C. It was observed that there was considerable decrease in specific fuel consumption when air was bubbled through water. The exhaust gas was analysed and it indicated a decrease in temperature and an increase in percent fuel efficiency and oxygen.

1. INTRODUCTION:

The use of water in fuel oil emulsion or the water introduction into the engine combustion chamber has been an ancient practice. In the second world war, many aeronautical piston engines used water injection to improve take-off power. Further researchers have recommended the water introduction as a means to reduce ignition shock and the mean temperature generated within the combustion chamber. For several years, burners using water in fuel oil emulsion have been used with the following advantages [1].

(i) Unburned carbon is dramatically decreased.
(ii) Fuel consumption is improved.
(iii) Corrosion danger is partially removed because

sulphuric anhydride and dew point are diminished.

(iv) Excess air is reduced.

(v) CO_2 and NOX contents of smoke are reduced.

(vi) Furnace cleaning is made easier due to the little, powdery and non-adhesive soot and deposits.

Current researchers of England, Japan, Germany and other nations have spent time to investigate engine operation with water in fuel oil mixture. The main aim of these researchers were to observe the effect on specific oil consumption, soot formation, grade of smoke or NOX. In all these experiments, water has been introduced into the engine combustion chamber by one of the following means:

(i) Mixture with fuel oil.

(ii) Water in fuel-oil emulsion.

(iii) Separate injection.

(iv) Via inlet manifold.

It has been observed by the various investigators [2], [3],[4] and [5], that the best method to introduce water in engine combustion chamber is water in fuel oil emulsion. Due to the non-systematic studies as reported in the literature, it is not possible to state that the I.C. engines may run free from the troubles with mixtures or emulsions of water and fuel oil. Further, there are also different views on the mechanism which governs water-fuel oil combustion phenomena and the influence of water droplet dimensions.

The main stress of these investigations is laid on making of water-in-oil emulsions and their combustion.

The following observations are reported by the investigators[6]:

(i) The water must be evenly dispersed in the oil so that, by atomisation of the oil, there is water in all the larger oil drops.

(ii) The emulsion must be burned within 15 minutes from the making, since the effect (reduction of particulate) decreases with time.

(iii) Certain additives increase the effect of the water-in oil emulsion.

(iv) By the process of atomisation of water through a pressure jet nozzle into the oil, the effect is increased with higher water pressure.

(v) The effect of water is not a chemical one, but physical. Secondary atomization of the oil droplets results as they are heated in the combustion chamber.

(vi) If the water content is limited to 5%, the amount of water is very small compared to the amount of water generated during the combustion and the amount carried with the combustion air. Hence, there is no risk of corrosion.

(vii) Dispersion of water in oil proved to give very substantial reductions of the oil coke emission and soot formation.

2. EXPERIMENTAL SET-UP

Schematic diagram of the experimental set-up is shown in Fig.1. A Honda EM-500 generator with the specifications as AC 220V, 50 HZ, rated 330 VA, Max. 400 VA was used. The air inlet of the engine generator was connected to a glass flask of 5.0 litre capacity with the help of a plastic pipe. Atmospheric air was made to pass through the central tube fitted to the flask and was bubbled through the water in the flask. The transparent glass flask had four openings. Besides connecting the inlet of the generator through a plastic duct to a tight tube through one of the openings, another tube connecting the atmosphere to a level just below the water surface was used. This enabled the inlet air to be saturated with moisture and then proceed to the engine. The third opening was fitted with a thermometer which helped to measure the air temperature inside the flask and the fourth opening measured the humidity with the help of a hygrometer. The glass flask was kept on an electric heater with temperature regulator. Water temperature inside the flask was varied from atmospheric temperature upto 52 °C during the different experimental runs. During each run, 250 CC of fuel was used up in the engine generator. A measuring device used with an auxiliary fuel tank indicated the quantity of fuel fed to the engine. The engine generator was loaded in steps with the help of a lamp load of maximum 5 bulbs (100W each). This lamp load was connected through a precision grade wattmeter. The exhaust gas analysis was carried out with the help of a digital fuel efficiency monitor.

During the experimentation, Honda generator was switched on. The inlet air was moisturised by bubbling through water and was sucked in through the air suction inlet. The time for specific quantity of fuel consumption was noted. Wattmeter reading was also noted. The exhaust gas was allowed to pass through a long metallic pipe to the atmosphere. At one end of the pipe, fuel efficency monitor was used which read a digital output of % oxygen, Exhaust gas temperature and % Efficiency.

The Fuel Efficiency Monitor is a product of Neotronics Energy conservation division. Percent efficiency in this unit is expressed as follows:

% Efficiency = 100-[Radiation loss + Dry flue gas loss + Loss to moisture and Hydrogen]

$$= 100-[RL + K_1T/(21-\%O_2) + K_2(1121.4 + T)]$$

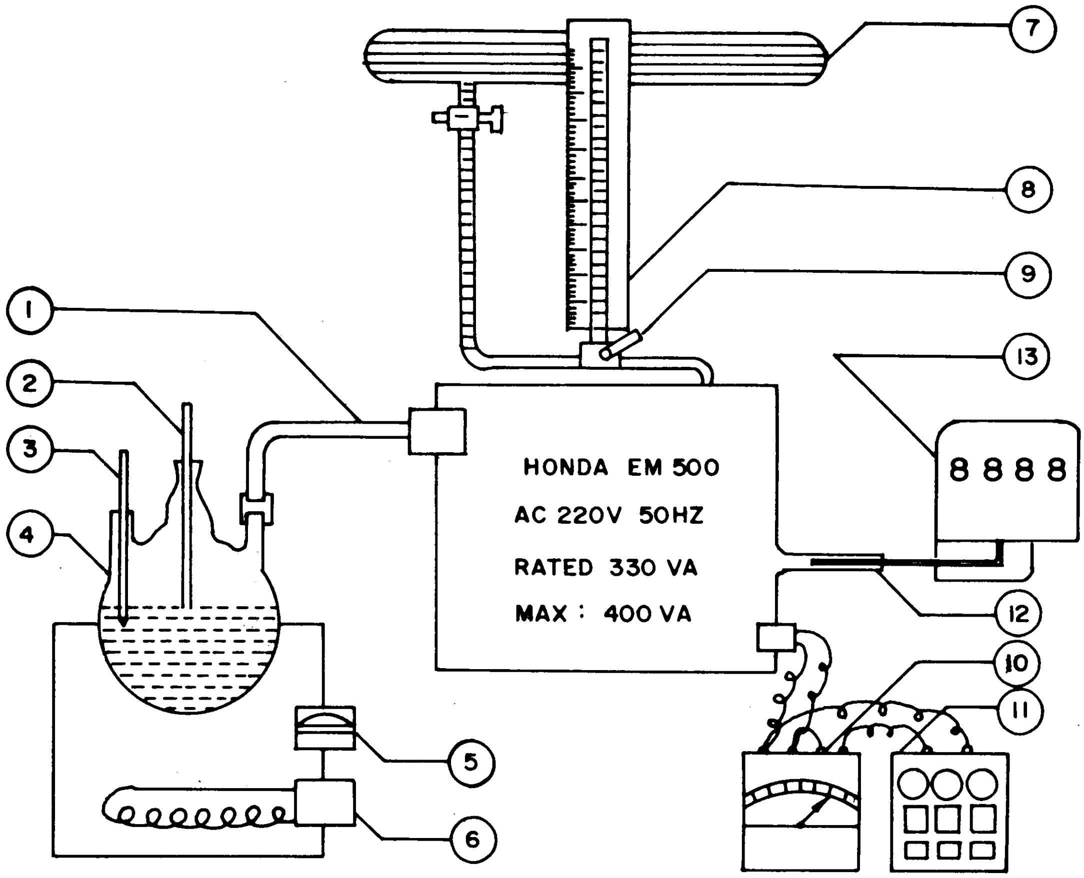
Where

RL = Radiation loss which is set at 3%

K_1 = 0.712 for fuel oil

T = Differential temperature, deg.C (Flue gas temperature-Air temperature)

K_2 = 0.00512 for fuel oil



1. INLET TO HONDA GENERATOR
2. AIR INLET
3. THERMOMETER
4. FLASK FOR BUBBLING AIR THROUGH WATER
5. TEMPERATURE REGULATOR
6. HEATING MANTLE
7. FUEL TANK
8. FUEL MEASURING DEVICE
9. ALTERNATE CONNECTION TO ENGINE
10. WATT METER
11. LAMP LOAD
12. EXHAUST PIPE
13. FUEL EFFICIENCY MONITOR

FIG. 1 SCHEMATIC DIAGRAM OF THE EXPERIMENTAL SET-UP

Calorific value (KJ/Kg) = 44181 (gross) and 41506 (net)

Firstly, the specific fuel consumption was measured at atmospheric temperature with and without moisturised air. In second set of experiments, the temperature of the water inside the glass flask was raised in stages and corresponding fuel consumption was recorded.

3. RESULTS AND DISCUSSION:

Present investigation used a new Honda generator for experimental studies. Therefore, the engine was tested first of all for its consistent performance by noting its output for 250 cc petrol at its full load without using moisturised air. Nearly 25 data runs were obtained which stabilized the output from the engine. Experimental runs were subsequently carried out for two types of operation namely, with air bubbling through the water and with direct atmospheric air getting into the system. The values of fuel consumption and output wattage were recorded and used to calculate the specific fuel consumption (cc/hr.W) for a given load condition.

Fig.2. represents a graph of specific fuel consumption vs output of the engine with and without the introduction of moisturised air through the engine. This is a typical graph obtained out of the many which were drawn at different loads varying from 180 W to 375 W. The following are the notable features.

(i) With an increase in load, the specific fuel consumption always decreases both with and without the use of moisturised air.

(ii) Specific fuel consumption of the engine is less when air is moisturised by bubbling through water and this is observed to be so at all load conditions.

(iii) At lower values of the engine output, the specific fuel consumption is slightly less with the use of moisturised air but as the output of the engine approaches towards its maximum, there is considerable reduction in the specific fuel consumtpion.

From the above observations, it is seen that there is improvement in the fuel consumption by bubbling air through the water before sending it to the carburettor. This is in confirmity with earlier experiments on burners, with combustion air passing through the water and about fifteen percent improvement in thermal efficiency is recorded [7].

Fig.3 is a plot of specific fuel consumption vs. temperature of the water bath at 200W engine output. This graph indicates a decrease in fuel consumption upto a temperature of 47^{o}C beyond which it tends to increase. Similar behaviour was also shown at other engine outputs varying up to the full load of 375W.

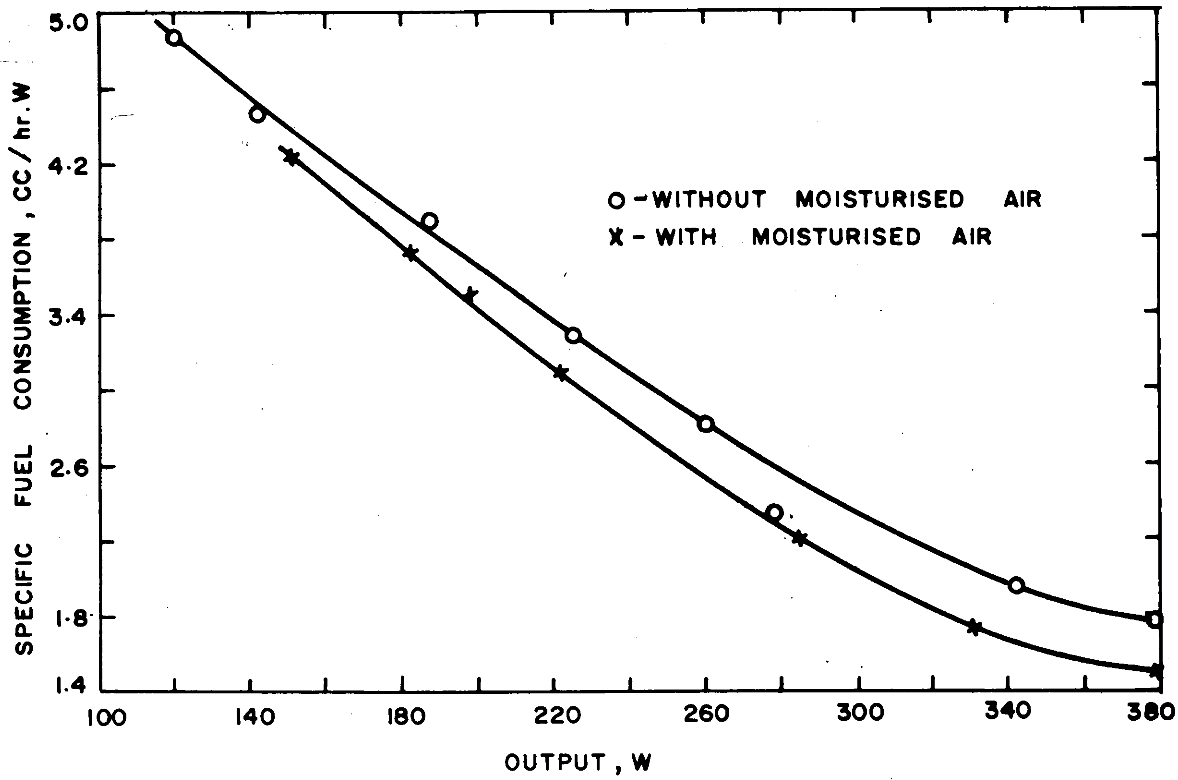


FIG. 2 SPECIFIC FUEL CONSUMPTION Vs OUTPUT AT ATMOSPHERIC TEMPERATURE

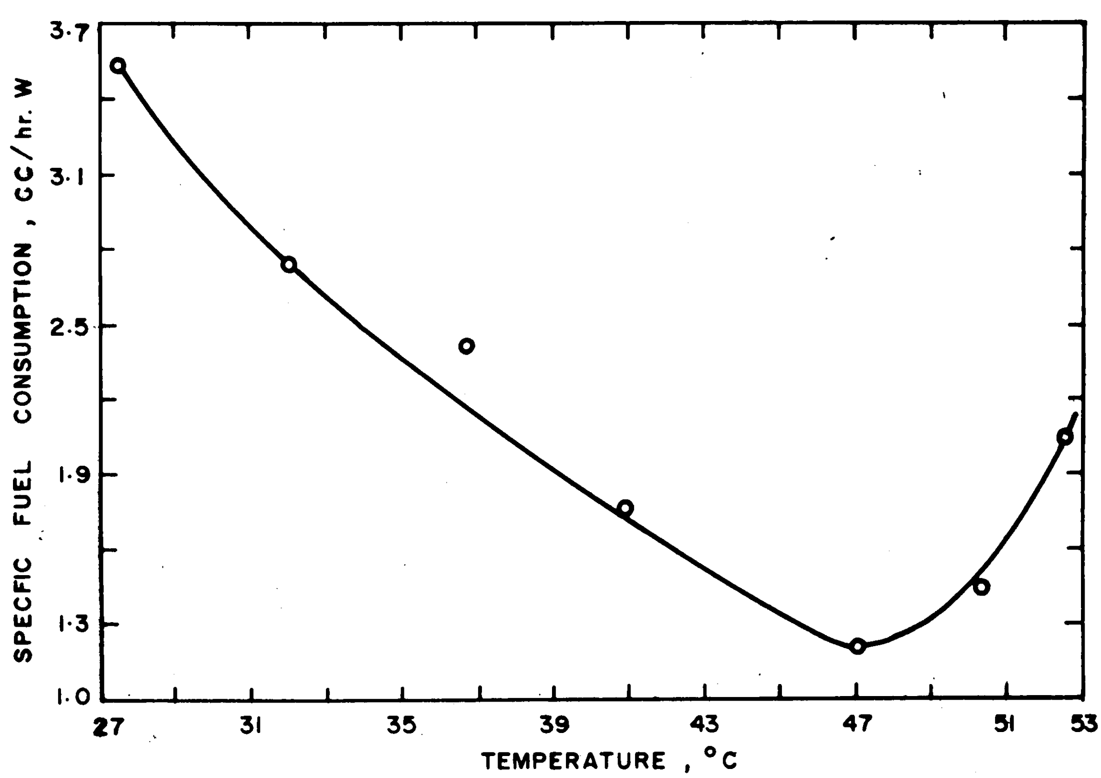


FIG. 3 VARIATION OF SPECIFIC FUEL CONSUMPTION WITH TEMPERATURE AT 200W OUTPUT

Further, it was noticed that the temperatures beyond 47°C inside the water bath caused erratic running of engine resulting in heavy fluctuations in output. It is therefore considered not advisable to go for such operations.

Digital Fuel Efficiency Monitor recorded the data in each experiment. Table-1 is a specimen of such observations.

TABLE-1

FEM Reading	Atmospheric Air	Moisturised Air
% Efficiency	72.4	76.5
Temperature (°C)	164.0	152.0
% Oxygen	13.7	14.4

The above Table indicates an increase in per cent efficiency and oxygen content of the exhaust gas and a decrease in temperature, while using moisturised air. Literature [8] and [9] report that air gets ionized when sprayed or bubbled through water and there is a presence of OH_3^+ ion in water [10]. In this context, a number of possible reactions, endothermic/exothermic with excited atoms/ions are suggested. A suitable device to monitor the ions and atoms may help to understand the mechanism through which the improvement in combustion is achieved.

4. CONCLUSIONS:

Several experimental trials, carried out in this first stage of research on the effect of moisture on the performance of I.C. Engine reveal the following:

(i) The operation of petrol engine is quite smooth and trouble free while working on moisturised air.

(ii) The fully saturated air offers definite advantage in reducing the specific fuel consumption over the entire operating range of the engine.

(iii) The reduction of exhaust temperature decreases the thermomechanical load. Thus, engine reliability improves and perheps, allows to reduce excess air and there by raise the specific power output.

The mechanism by which bubbling combustion air through water reduces the specific fuel consumption apparently involves the alteration of the combustion kinetics as a secondary effect of the process of breaking the water surface. The production of electrical charge at the air-water interface in the bubbling process appears to be the source of ions which enter into the combustion process. This explanation is supported by the several experimental and theoretical investigations in the area

of Physics and Chemistry over the past one century. The present investigation clearly indicates that an I.C.Engine may run better with an addition of small amount of water by using an appropriate feeding technique which not only saves energy and money but also reduces pollution. Further, the systematic investigations on various aspects of the present research using powerful tools and measurement techniques are in progress at Regional Engineering College, Tiruchirapalli.

5. REFERENCES:

[1] -Enrico Chiappini, " Operation of Automotive Diesel Engine with Water in Oil Emulsion ", Proceedings of the contractors Meetings, Brussels, Oct., 21-28,1982.

[2] -Agosta, V.," Diesel Fuel Emulsifier Systems ", Proceedings of ISATA'77, Wolfsburg, Sept.12-15,1977.

[3] -Bignardi,L. and et al., " Products of Combustion of Water in Fuel Emulsion", Proceedings of 14th CIMAC, Helsinki, 1981.

[4] -Naegeli, D.W., and Moses, C.A., " Fuel Microemulsions for Jet Engine Smoke Reduction" , ASME 82 - Gl - 33, 1982.

[5] -Chiappini,E., Tomasini, E.P., " Sul Funzionamento Di Un Motore Diesel Veloce conasolio Emulsionato" , Pubbl. no 25, Intituto Di Meccanica e Macchine, Un.L' Aquila, March, 1979.

[6] -Sjogren, A, " Burning of Water-in-Oil Emulsions" , Sixteenth International Symposium on Combustion, Massachusetts, The combustion Institute, 1977.

[7] -Nelson, K.L., and et.al., " Augmentation of Gas-Phase Combustion By Bybbling Combustion Air Through Water" , Alternative Energy Sources IV, Vol.6, Edited by T.Nejat Vezirorglu, Ann Arbor Science Publishers, Michigan, 1982.

[8] -Alty.T., " Origin of Electrical charge on Small Particles in Water" , Proceedings of the Royal Society (London), Vol.122, Ser.A, 1926.

[9] -Nolan, J.J.," Electrification of water by Splashing and Spraying" , Proceedings of the Royal Society (London), Vol.90, Ser.A., 1914.

[10] -Bernal, J.D., " A Theory of Water and Ionic Solution with Particular Reference to Hydrogen and Hydroxyl Ions" , Journal of Chemical Physics, Vol.1, pp.515-548,1933.

THEORETICAL STUDY OF OXYGEN INJECTION AS A METHOD OF INCREASING THE SPECIFIC POWER OF PISTON ENGINES

B.A. Aburwin and A. Bawadi

Al-Fateh University, Tripoli, GSPLAJ.

ABSTRACT

The conventional methods of supercharging the internal combustion engines have disadvantages concerning thermal and mechanical stresses due to excessive pressure in the engine cylinder. Also, matching problems at part load require complicated control systems which cause a loss of power and extra cost. The present paper proposes an alternative method of increasing the specific power of the internal combustion engines by Oxygen injection in the intake manifold. Theoretical study shows that the proposed method overcomes disadvantages of the conventional methods.

Notations:

D	Cylinder diameter (m)
K	isentropic index
m	mass (kg)
N	velocity of rotation (rev/s)
N_e	power (KW)
P	Pressure (bar)
	pressure ratio of the compressor
R	Gas constant
$_{NU}$	ratio of nitrogen to oxygen by volume of the air charge
s	piston stroke
T	temperature (^oK)
V	Cylinder volume (m^3)
xF	percent of heat added at constant volume.
η	efficiency
ε	compression ratio

Subscripts:

a	ambient	as	air in the cylinder when supercharged
a_n	naturally aspirated	an	air in the cylinder when naturally charged
c	compressor	os	oxygen in the cylinder when supercharged
max.	maximum	act	actual
s	supercharge		
th	thermal		

Introduction:

The most effective means of increasing the specific power output of the Internal Combustion Engines, besides an increase of the mean piston speed, is the raising of the mean effective pressure of the cycle by increasing the charge weight. The increase of the charge weight (supercharge) is most easily accomplished by raising the density of the charging air supplied to the engine, which can be handled by superchargers of various types.

The exhaust gas turbochargers has been employed widely. By utilizing the exhaust gas energy in the exhaust gas turbine, it is generally possible to provide all the power needed for driving the compressor from the turbine.

The maximum permissible degree of supercharging is usually determined by considerations of thermal loading, economics, strength and satisfactory matching of the compressor, the engine, and the turbine.

Generally, the power consumption of the compressor at design condition is of the same order as the power output of the exhaust gas turbine. There are however, operational conditions at which the energy balance between the compressor and the exhaust gas turbine deteriorates. Therefore, a control system has to be provided for matching reasons to maintain the desired energy balance and the strength limit to avoid overload. These methods are expensive, complicated, and moreover cause a loss of energy.

The present paper suggests a method of increasing the specific power of the internal combustion engines by oxygen injection in the inlet manifold. This method is utilized only when the power required from the engine exceeds the rated power of air aspirated engines. In this case, matching problems of supercharging at part loads will be avoided. Theoretical study is carried out and a comparative analysis is given between the turbocharging and the proposed method.

Theoretical Considerations:

In order to compare the proposed method of increasing the specific power of the engine with the conventional method (supercharging), the mass of oxygen inside the cylinder is maintained the same in both cases, while the mass of Nitrogen in the cylinder by the proposed method is less than that by the conventional method. The Nitrogen Oxygen ratio (RNO) is altered and can be calculated by the following formula:

$$RNO = \left[\frac{\frac{1}{nc}\left(r^{\frac{k-1}{k}} - 1\right) + 1}{0.233\ r} - 1 \right] \frac{32}{28}$$

and the corresponding mass of Oxygen which should be injected (m_{iO_2}) is obtained from the expression:

$$\frac{m_{iO_2}}{(m_{a_n})_{act}} = \frac{1 - 0.266\ RNO}{1 + 0.875\ RNO} \qquad (2)$$

The derivation of the above expressions is given in an Appendix.

Results and Discussion:

A theoretical study of the proposed method is carried out by analyzing the thermal cycle of a diesel engine having the following specifications:

D = 0.08 m

s = 0.88 m

N = 50 r.p.s

The mathematical model used is for a dual cycle 1 with the proper modifications for supercharging and Oxygen injection parameters.

The study has been carried out for different operating conditions as given in Table (1).

Table (1): Study variables for computer calculations

Test No.	P_s	T_c	RNO	$m_{iO_2}/(m_{a_n})_{act}$	Remarks
1	1.0	300	3.76	-	Naturally aspirated
2	1.5	346	3.76	-	Supercharge
3	2.0	382	3.76	-	Supercharge
4	2.5	412	3.76	-	Supercharge
5	1.0	300	2.67	0.087	equivalent to test No.2
6	1.0	300	2.02	0.167	equivalent to test No.3
7	1.0	300	1.59	0.241	Equiv.to test No.4

The above data is used to calculate the thermal cycle for

a) xF* = 0.2 0.3 and 0.5 and
b) ε = 14.0 16.5 and 20.0

*indicates the reference number.

The results of such calculations are given in Table (2) which shows percentage variation of the maximum pressure, maximum temperature, power output, and the thermal efficiency due to supercharging and Oxygen injection relative to the naturally aspirated operation with xF = 0.5 and ε = 16.5, 14.0 and 20.

The comparison between the given two methods of increasing the specific power of the engine (without taking into account the power absorbed by supercharger) indicates:

1) For the same engine and
   a) the same power output: the proposed method of Oxygen injection has the following particulars (relative to supercharging):

Table (2): Comparative calculated results of the performance parameters, a) ε = 16.5

xF	P_s	% increase (supercharging)				% increase (Oxygen injection)			
		P_{max}	T_{max}	N_e	th	P_{max}	T_{max}	N_e	th
0.5	1.5	36.0	3.0	29.2	0.0	13.9	11.4	25.5	- 3.1
	2.0	69.9	5.4	55.1	-1.1	26.4	20.5	48.7	- 5.5
	2.5	102.0	7.4	79.2	-1.5	37.6	28	69.9	- 7.6
0.3	1.5	8.9	0.0	25.5	-3.4	-11.8	7.8	21.3	- 6.3
	2.0	37.5	2.3	51.3	-3.8	- 3.5	16.8	43.4	- 8.9
	2.5	65.0	4.3	74.4	-4.1	4.0	24.1	63.5	-11.1
0.2	1.5	- 5.6	-1.7	22.6	-5.7	-26.0	5.9	17.7	- 9.0
	2.0	20.0	0.07	47.7	-5.9	-20.0	14.7	38.7	-12.2
	2.5	45.0	2.7	70.7	-6.2	-14.7	21.9	57.7	-14.2

I) lower maximum pressure

II) higher maximum temperature

III) lower efficiency

b) ε = 14.0

xF	P_s	% increase (supercharging)				% increase (Oxygen injection)			
		P_{max}	T_{max}	N_e	th	P_{max}	T_{max}	N_e	th
	1.0	-15.8	-1.2	- 2.7	- 3.7				
	1.5	14.3	1.6	25.5	- 4.3	-3.9	10.2	21.7	6.8
2.0	2.0	42.5	3.9	50.7	- 4.8	6.9	19.5	44.2	- 9.4
	2.5	69.6	5.8	70.3	- 5.2	16.5	27.0	64.7	-11.3
	1.5	- 9	-1.4	21.7	- 7.3	-26	6.8	17.3	-10.2
0.3	2.0	14.7	0.88	46.3	- 7.7	-18.8	15.8	38.7	-12.8
	2.5	37.5	2.7	69.4	7.9	12.3	23.1	57.9	14.9
	1.5	-21.6	-3	18.4	- 9.7	-38	4.8	13.5	-13.2
0.2	2.0	0.0	-0.8	42.5	- 9.9	-33	13.7	33.8	-16
	2.5	19.6	1.08	65.0	-10.1	-28	20.9	51.8	-18.3

c) ε = 20.0

xF	P_s	% Increase (supercharging)				% increase (Oxygen injection)			
		P_{max}	T_{max}	N_e	th	P_{max}	T_{max}	N_e	th
	1.0	22.7	1.5	3.1	4.2				
	1.5	67.2	4.8	33.2	3.5	39.3	12.7	29.7	1.15
0.5	2.0	109.1	7.3	60.2	3	54.3	21.8	54	-1.37
	2.5	149.1	9.4	84.7	2.6	67.6	29.2	76	-3.4
	1.5	35.0	1.7	30.0	0.9	85	9.3	25.5	-1.9
0.3	2.0	70.0	4.3	56.3	0.5	18.6	18.1	48.8	-4.5
	2.5	104.9	6.4	80.0	0.2	27.5	25.3	70.0	-6.8
	1.5	17.7	0.0	27.2	-1.2	- 8.2	7.4	22.5	-4.4
0.2	2.0	50.0	2.6	53.2	-1.5	- 1.2	16.1	44.5	-7.3
	2.5	81.1	4.7	77.0	-1.7	5.2	23.1	64.5	-9.7

(b) the same maximum pressure; the proposed method has:

I) higher power output

II) higher maximum temperature

III) lower efficiency

(c) The same power output and the maximum pressure: The quantity of heat added at constant volume must be reduced in case of supercharging. This can be achieved by controlling the fuel injection characteristics in the actual engine. This will make the efficiency of both methods approximately the same with slight decrease in the maximum temperature in case of supercharging.

2) In order to keep ;the same maximum pressure and obtain approximately the same power output, the compression ratio of the engine must be decreased with supercharging, while it increases with Oxygen injection. An improvement in thermal efficiency is obtained in the suggested method.

Conclusion and Suggestions for further work:

The proposed method of increasing the specific power of the internal combustion engines reduces the maximum pressure in the engine cylinder, but still has some problems in connection with the maximum temperature and thermal efficiency. Practice in designing the I.C.E. shows that the most decisive factor is the maximum pressure in the engine cylinder, which makes the suggested method more advantageous than the conventional method of supercharging. This requires deeper investigation and proper evaluation of the two methods of increasing the specific power of the engine taking into consideration the following:

a) heat transfer between the working medium and the engine cylinder.

b) rate of heat addition due to injection, preparation and reaction, rates of the fuel in the engine cylinder.

c) power consumed by supercharger.

References:

1. R.S. Benson and N.D. Whitehouse,"Internal Combustion Engines", Pergamon Press, 1979, England.

2. H.R. Ricardo and J.G.G. Hempson, "The High speed Internal Combustion Engine", 5th ed. Blackie, 1968.

3. F. Schmidt, "The Internal Combustion Engine", Chapman and Hall, 1965.

Appendix:

Theoretical Considerations:

The development of the expressions for RNO and the mass of Oxygen Injection by the proposed method is given below keeping the same mass of Oxygen in the cylinder for both methods.

The mass of air in the cylinder when supercharged

$$(m_{as}) = \frac{P_s\ V \times 10^5}{T_c\ R}$$

$$m_{os} = 0.233\ m_{as} = 0.233\ \frac{P_s\ V \times 10^5}{T_s\ R} \qquad (1)$$

The mass of air in the cylinder when naturally aspirated

$$m_{an} = \frac{P_a\ V \times 10^5}{T_a\ R} \qquad (2)$$

The mass of nitrogen available in the cylinder when Oxygen injection is used keeping the same Oxygen in both methods.

$$= m_{an} - m_{os}$$

The mass of oxygen induced from atmosphere

$$= \frac{(m_{an} - m_{os})}{0.767} \times 0.233$$

and the mass of O_2 which is injected to compensate the total mass of O_2 $(m_{inj})^2$

$$= m_{os} - \frac{(m_{an} - m_{os})}{0.767} \times 0.233$$

$$= \frac{m_{os} - 0.233\ m_{an}}{0.767}$$

RNO by oxygen injection proposed method:

$$\text{RNO} = \frac{(m_{an} - m_{os})}{m_{os}} \times \frac{32}{28} \qquad (3)$$

$$= \left(\frac{m_{an}}{m_{os}} - 1\right) \times \frac{32}{28} \qquad (4)$$

Substituting for m_{os} from eqn. (1) and m_{an} from eqn. (2) in eqn. (4)

$$\text{RNO} = \left(\frac{T_c\ P_a}{0.233\ T_a\ P_s} - 1\right) \times \frac{32}{28}$$

Since

$$\frac{T_c}{T_a} = \frac{1}{c}\left(r^{\frac{k-1}{k}} - 1\right)$$

Where

$$r = \frac{P_s}{P_a}$$

$$RNO = \frac{c\left(r^{\frac{k-1}{k}} - 1\right) + 1}{0.233} - 1 \times \frac{32}{28} \qquad (5)$$

From eqn. (3) the ratio

$$\frac{m_{iO_2}}{(m_{an})_{act}} = \frac{\frac{m_{os}}{m_{an}} - 0.233}{0.767}$$

From eqn. (4)

$$\frac{m_{os}}{m_{an}} = \frac{32}{28\ RNO + 32}$$

$$\frac{m_{iO_2}}{(m_{an})_{act}} = \frac{\frac{32}{28\ RNO + 32} - 0.233}{0.767}$$

Simplifying the equation:

$$\frac{m_{iO_2}}{(m_{an})_{act}} = \frac{1 - 0.266\ RNO}{1 + 0.875\ RNO} \qquad (6)$$

"TOTAL ENERGY CONCEPT : AN IDEA WHOSE TIME HAS COME"

P.C. AGRAWAL,
DEPT. OF MECH. & PROD. ENGINEERING,
BRIGHT STAR UNIVERSITY OF TECHNOLOGY,
P.O. BOX 58158,
AJDABIA, (LIBYA).

ABSTRACT

Total energy concept or cogeneration is a method of producing electricity and thermal energy from a single source of fuel and consists of a prime mover, an alternator, devices of making the waste-heat usable and control & safety devices. The main applications of total energy systems are in heating of buildings and in paper and pulp, food processing, textile, chemical petroleum refining, and steel industries. The advantages of total energy systems are in independent from grid systems, reduced cost in erection of power transmission lines and better utilisation of waste heat. The disadvantage of total energy systems are in high initial capital investment, noise, vibration, smoke, fuel storage problem, and requirement of more skilled personnel. The economic feasibility of total energy system depdends on equipment cost, load factor, maintenance cost, standby requirements, use of recoverable heat, taxes and financing arrangements. Total energy systems are successful when power prices are high, fuel prices are low, steady demand of heat and low standby requirement.

INTRODUCTION

The production and distribution of electricity today is an extremely wasteful process. During the conversion of fuel to electric power at cent-ralised power stations more than 60% of the heat content of fuel is thrown away unsightly and expensive cooling towers. Besides this, distribution of electricity is most expensive and least desirable way of distribution to any public utility due to need of massive overhead power lines. Therefore, now a days it has been realized that it is often cheaper to manufacture one's own

electric power and to use the waste heat produced during the manufacturing process than to buy power from the central undertakings. This is what the Total Energy or Cogeneration is i.e. a method of producing electricity and thermal energy from a single source of fuel. It is completely a new concept and unknown before 1950. The large power generating companies, too, are realising that they can no longer afford to throw away all their waste heat. They have started to utilise their waste heat for heating the buildings and various other industrial applications such as in pulp and paper, food processing, textile, chemical petroleum refining and steel industries that share large requirements for both electricity and steam.

The scope of development of total energy schemes can be seen from this that in 1964 only 175 total energy schemes were in operation in USA, which rose to 600 by 1968 and 25000 by the end of 1978. It is expected that presently about 2,00,000 total energy schemes are in operation in USA alone. Western world, specially West Germany, Norway and Sweden have made considerable progress in this field. Western European countries, USSR and Japan have also applied the total energy concept in their industries with varying degree of success.

(2) WHAT IS TOTAL ENERGY ?

The production of electricity from the combustion of natural fuel in the form of chain reaction can be shown as below:

Fuel $\longrightarrow$ Heat $\longrightarrow$ Mechanical Energy $\longrightarrow$ Electricity.

The weakest link in this chain of reactions is conversion from heat to mechanical work and even in the most perfect system it is limited by Carnot's cycle efficiency

$$\eta_c < \frac{T_1 - T_2}{T_1} \qquad \text{———} (1)$$

where T_1 and T_2 are the highest and lowest temperatures of the system in K. Modern steam turbine plant can operate with steam at upto 580° C (853 K) and exhaust the steam at temperature as low as 30° C (303 K) and the theoretical limit of the conversion of heat into mechanical energy with such a system is

$$\eta_c = \frac{853 - 303}{853} = 64.5\% \qquad \text{———} (2)$$

However, due to the facts that steam as a vapour deviates considerably from ideal gas laws and requirement of superheating the steam to avoid sedimentation and corrosion of turbine blades, and for many other reasons, the actual practical efficiency of the most modern steam plant hardly exceed than 35%. For low pressure steam turbines the efficiency is very low. As recently as 1963, the Oxford power station, U.K., operating with a steam feed temperature of 340° C (613 K)

and pressure of 17.4 bar had an operating efficiency of only 8.07%.

According to the first law of Thermodynamics, the total heat input to the system is equal to the total heat (or the other forms of energy) output. Then the question arises what has happened to the remaining energy contained in the fuel ? It has converted into heat and part of it is lost by radiation from the boiler plant and as sensible and latent heat in the flue gases. In most of the cases the quantity of energy lost in this is much greater than the energy usually converted into electricity.

Total energy operation seeks to obtain electricity in a way that uses nearly all the energy contained in the fuel instead of only a small fraction of this energy. There are several ways of doing this, Figure (1) shows the schematic arrangements of conventional power generation and total energy generation.

(3) ESSENTIAL COMPONENTS OF A TOTAL ENERGY SYSTEM:

A total energy system has the following components:

A prime mover which has an output consisting of a shaft power together with heat energy. As an alternative this prime mover may be replaced by a fuel cell, where the output is in the form of electricity plus heat energy. As mechanical power can be converted into electrical energy at almost no thermodynamic loss, these two types of system are quite comparable.

A device which converts mechanical energy into electrical energy. This is normally an alternator, which is of completely conventional design.

Methods or devices of making the waste-heat usable. This include heat boiler, drying equipment, absorption air conditioners etc.

Total energy installation must have appropriate control and safety devices to run the plant effectively.

(4) APPLICATIONS OF EXHAUST HEAT FROM TOTAL ENERGY PRIME MOVERS:

Waste heat from total energy prime movers can be converted into process heat which can be used by a wide varities of industries such as chemical, textile, paper and pulp, steel, petroleum refining, and food processing. The chemical industry uses large quantities of process steam for distillation, fractionation, evaporation, and other unit processes. Food processing, Breweries, laundries, gas works and many other industries are ready consumers of waste heat. Table (1) shows the effect on overall efficiency by coupling the gas turbine with condensing steam turbine. It can be seen that overall efficiency of coupled system increases by 9%.

TABLE 1 : CHARACTERISTICS OF GAS TURBINE AND GAS TURBINE COUPLED WITH STEAM ENGINE

S.N.	Characteristics	Gas turbine alone	Gas turbine coupled with steam turbine
(1)	Gas turbine inlet temperature	820° C	820° C
(2)	Exhaust Stack temperature	400° C	188° C
(3)	Exhaust stack loss	74.5%	37.3%
(4)	Condenser loss	-	27.2%
(5)	Overall efficiency	23.5%	32.5%

Manufacture of bricks, tiles, ceramics, glass, and leather are the industries where exhaust gases from total energy prime movers can be directly used for drying purposes. 16% overall saving in the operational cost with a supply of 18 GJ/hour of heat has been reported by a British Ruston and Hornsby gas turbine plant (installed in 1962) at brickworks at Macon, Georgia, U.S.A.

The waste heat from prime movers can be utilised to digest the sludge and to produce the methane from it. Such a plant has been installed at Beakton, Essex, U.K., with 8 gas turbines and blowers and has shown 1/4 million hours of satisfactory operation with saving of \$ 1200 per day in fuel cost.

The main application of waste heat can be in flash distillation process to convert saline and brackish water into drinking water. It has been found that it is feasible to design a nuclear power station operating on total energy principle to produce 400 M W of electricity and to supply 12,83,000 m^3 of fresh water per day with competitive costs of traditional methods of collecting and storing the rain water.

Space heating of dwellings, industrial and commercial complexes, schools, and hospitals is the best way of making use of low grade heat produced as a by-product of electricity generation system. Leningrad has one of the largest of the Russian systems of district heating and has been working satisfactorily since 1924. Table (2) shows some important data of Leningrad system as applying on 1 January, 1966.

TABLE 2 : SOME IMPORTANT DATA OF LENINGRAD HEATING SYSTEM.

(1)	Capacity of district heating network.	11.7TJ/hr.
(2)	Length of heating network.	562 km.
(3)	Number of connected buildings.	6427
(4)	Total heat delivery during 1965.	36,400 TJ
(5)	Total hot water delivery 1965.	70,000 TJ
(6)	Installed electrical capacity of ITOC turbines of system.	656 M W.
(7)	Electrical power output of ITOC turbines during 1965.	4.346×10^9 kWh.
(8)	Number of boiler houses.	20
(9)	Capacity of hot water storage tanks.	10,000 m^3
(10)	Number of turbine plants.	25
(11)	Fuel Consumption.	0.342 kg. of coal/kWh.
(12)	Ratio of electrical output/ heat supplied.	76 kWh/GJ

(5) ADVANTAGES OF TOTAL ENERGY SYSTEMS:

The main advantage of total energy system besides, efficient utilisation of waste heat and increased efficiency is that, it is independent from grid system. The event which gave total energy its greatest boost in the United States was the catastrophic power breakdown in New York and the New England States on 9 November, 1965 which caused the entire system to collapse affecting 2.125×10^5 km^2 of area and 30 million people. The overall cost to the community for this power failure was tremendous and only small isolated areas operating on total energy system could go normally. Therefore, now a days it has been realized that total energy plants with standby facilities is more reliable than the enormous super grid systems, where the breakdown of one major component can affect the entire system.

The cost of erection of power transmission line is considerably less in total energy system and therefore, the cost of transportation of energy is very less.

Total energy system can supply power at a variety of supply voltages and frequencies or can produce d.c. electricity if required. High frequency a.c. electricity is very useful in induction furances for metal treatment, flourscent lighting and dielectric heating etc. It is possible to have marked saving in current with high frequency. It has found at the McAllen High School in Texas, 452 kW of power was required for lighting the class with grid current at 60 hertzs. When the switch was made to a frequency of 840 hertzs using gas turbine total energy system, only 350 kW of power was required to meet the same lighting load.

The National Productivity Council (NPC) in collaboration with the Petroleum Conservation Research Association (PCRA), India, have done considerable field studies in the area of total energy and its application in Indian industries. Table (3) shows the result of study in savings/annum due to adoption of total energy system in different Indian industries.

TABLE (3) : SAVINGS PER ANNUM DUE TO ADOPTION OF TOTAL ENERGY SYSTEMS IN CERTAIN SELECTED INDIAN INDUSTRIES(7).

S.No.	Type of Industry	Saving/annum (million USD)*
(1)	Integrated paper mill of 220 tonnes/day capacity.	1.07
(2)	1500 tonnes/day fertilizer plant.	2.86
(3)	A 2.5 million tonnes/year refinery.	1.43
(4)	A composite textile mill.	0.71
(5)	Rayons Factory of 50 tonnes/day capacity.	1.43
(6)	Integrated steel plant.	3.57

* In conversion of Indian rupee (INR) into USD., 14 INR ≡ 1 USD. is taken.

The survey also envisaged that initial investments required to be made for adopting total energy systems could be recovered by the industries concerned in two or three years at most.

(6) **DISADVANTAGES OF TOTAL ENERGY SYSTEM:**

The main disadvantages of total energy system are:

(a) The initial capital investment of total energy system

per kW of installed capacity is often higher than at a central electricity station. The extra costs are incurred in providing premises such as special substation for the total energy equipments etc. However, considerable savings can be made in reducing provisions for running power transmission lines.

(b) Generally, small-scale consumers have to pay more (20-50%) for the purchase of basic fuel than the large central undertakings. Smaller plants also can't use fuel as effectively as do large plants. For e.g; a large conventional gas-fired steam-generating plant uses 0.31 m^3/kWh of natural gas as compared to 0.34 - 0.50 m^3/kWh of natural gas in small plants. On the other hand, there are better opportunities for small-scale plants to permit the proper utilisation of waste heat for various purposes than there is for large plants. If a total energy plant is installed to supply both a housing estate and an industrial consumer, it has been observed that a thermal utilisation efficiency of 80% can be achieved with such a well-matched and optimised systems.

(c) The total energy system requires stand-by unit. This is necessary to meet sudden increased load demand, but in any case it should not be more than 100%. On the other hand, there should be minimum penalty with the shrinkage of load as production cost rises considerably with the reduced load demand.

(d) In total energy system there is noise, vibration, smoke, and fuel storage problem which is not in the case of central power generation system. This is the strongest argument usually given against the installation of total energy system.

(e) Total energy system installation usually requires more technically qualified personnel as compared to in central power generation system.

(f) The cost of production in total energy system is not completely predictable and a lot has to be taken on trust, where the costs can not be foreseen with any degree of accuracy. In central power generation the cost of power production is completely predictable.

(7) ECONOMIC FEASIBILITY OF TOTAL ENERGY SYSTEM:

There are three basic considerations which determine whether the total energy system is economical than the purchase of electricity from the central undertakings:

(a) The equipment must be employed as fully as possible.

(b) The recoverable heat must be utilised well.

(c) Adequate quantities of relatively low cost fuel must be available.

All these three considerations gives a number of dependent variables such as equipment cost, gas and electricity costs, load factors, maintenance costs, stand-by requirements,

use of recoverable heat, taxes and financing arrangements. A thorough study of various dependent variables is required to get the cost of power production with certain degree of accuracy.

The economic feasibility of prime mover can be determined by simple payout method, i.e. how long it will take to recover the investment. The equation for simple payout in years is as follows:

$$\text{Payout (years)} = \frac{\Delta C}{H\left[E - (M + G - H_R)\right]} \qquad (3)$$

where : ΔC = incremental engine cost - USD/kW
H = operating hours per year.
E = Electric rate - USD/kWh.
M = maintenance cost - USD/kWh.
H_R = value of recoverable heat used - USD/kWh.

This method of payout is not an accurate measure of investment profitability and should not be used. However, it is adequate for the purpose of study because it affords a first approximation or screening of alternate investment possibilities.

A nomograph (figure 2) based on above payout equation has been developed by Northern Natural Gas Company, U.K. It is possible to determine annual saving/kW and payout period from this nomograph. Let us consider following values:

(a) Cost of electricity - 3 cents / kWh.
(b) Cost of gas - 2 USD. /100 m^3.
(c) Electric motor drives air compressor - 5,000 hrs/year.
(d) Engine maintenance cost - 2.75 USD./1,000kWh.
(e) Incremental engine cost - 90 USD./kW.
(f) Recoverable heat - 50% usable with the gas rate of 2 USD./100 m^3.

The procedure followed for the calculation of above values is as below:

(i) Connect recoverable heat used (50%) with the gas rate (2 USD./100 m^3) and locate reference point on (1) axis.

(ii) Connect reference point (1) with the maintenance cost (2.75 USD/1000 kWh) and locate reference point (2).

(iii) Connect the reference point (2) with electric rate (3 cents/kWh) and locate the reference point (3).

(iv) Connect the reference point (3) with annual operating hours (5000) and locate reference point (4) - yearly saving is 121.5 USD/kW.

(v) Connect yearly saving (121.5 USD/kW) with incremental engine cost (90 USD/kW) to determine the prime mover payout -

.65 years i.e. less than 8 months.

It is sometimes difficult to read the value to the desired accuracy because of the orientation of the payout line on the nomograph.

(8) C O N C L U S I O N :

In general, total energy system project must be approached on a case-by-case basis. Anybody interested in total energy system project must individually address many problems and answer a litany of questions before entering into small power production. These include viability of cogeneration, regulatory compliance, system design, capacity, utility interface, environmental impact, and probably the most important financing.

The Public Utilities Regulatory Policy Act (PURPA) of USA maintains fairly strictly qualifying standards in the areas of operation, efficiency, and ownership. The qualifying criteria depend on the energy product emphasis i.e. whether fuel energy is first used to produce electricity with rejected heat producing thermal energy (usually called a topping cycle) or the reverse (usually called a bottoming cycle), which first produces thermal energy. The USFERC (Federal Energy Regulator Commission) operating standard require that a new topping cycle must produce atleast 5% of the total energy output as useful thermal energy and for a new bottoming cycle, a system must produce an annual useful power output of atleast 45% of the energy input of oil or gas for supplementary firing to heat water of steam electricity production cycle.

In essence, presently the total energy systems have not been given full importance and they are likely to be successful when the power prices are high, fuel prices are low, steady demand of heat, and low standby requirement.

****

R E F E R E N C E S :

(1) Criner, Douglas E, " Cogeneration Economics: Utility and Industrial Perspectives" The Cogeneration Journal 1, 3: May, 1986; pp 52-63.

(2) Diamant, R.M.E., " Total Energy ". Pergamon Press, New York, 1981.

(3) Diamant, R.M.E., " Methods of Centralised Heat Generation " IHVE Symposium on District Heating, London, 21 - 22 March, 1987.

(4) Gauthier, C.J., " Marketing Total Energy ", The Institution of Gas Engineers, 33rd Autumn Research Meeting, November, 1967.

(5) Mulloney, J.A. Jr., " Small Scale Cogeneration Technology ", The Cogeneration Journal 1, 4, 1986, pp 59-70.

(6) Bhattacharya, D., " Waste Heat Recovery Through Cogeneration in Selected Industries in India ", Discussion Paper TERI, 1983.

(7) Seminar Proceedings on Total Energy and Energy Substitution NPC, 1973.

(8) Agrawal, R., " Role of Education in Energy Use Management " 12th Congress WEC, September, 1983.

(9) Smith, C.B., " Energy Management Principles, Applications, Benefits, Savings " Pergamon Press, 1981.

****

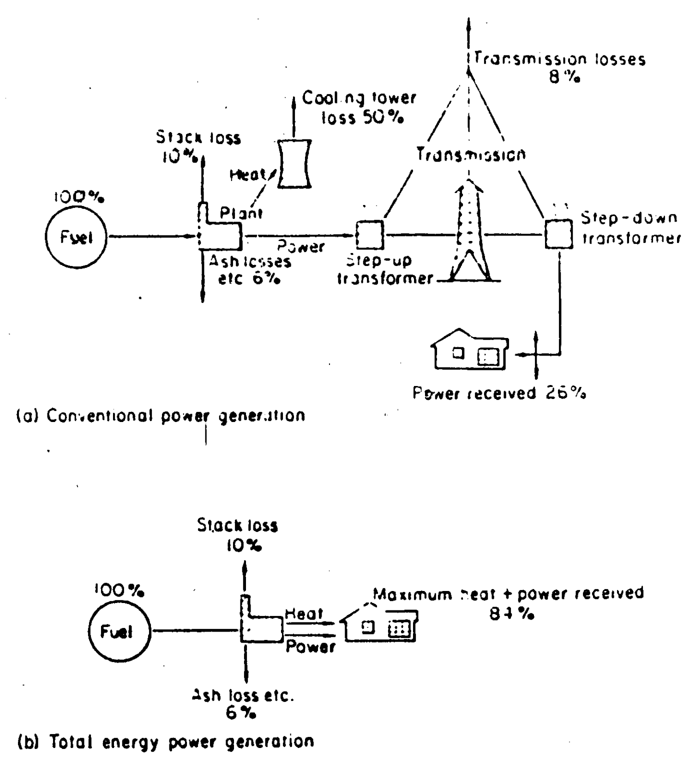


Figure (1) : schematic arrangements for conventional power generation and total energy system.

Based on the equation.

$$\frac{\Delta \text{Engine Cost}}{\text{Hrs}\left[\text{Elec} - (\text{Gas} + \text{Maint} - \text{HR.})\right]}$$

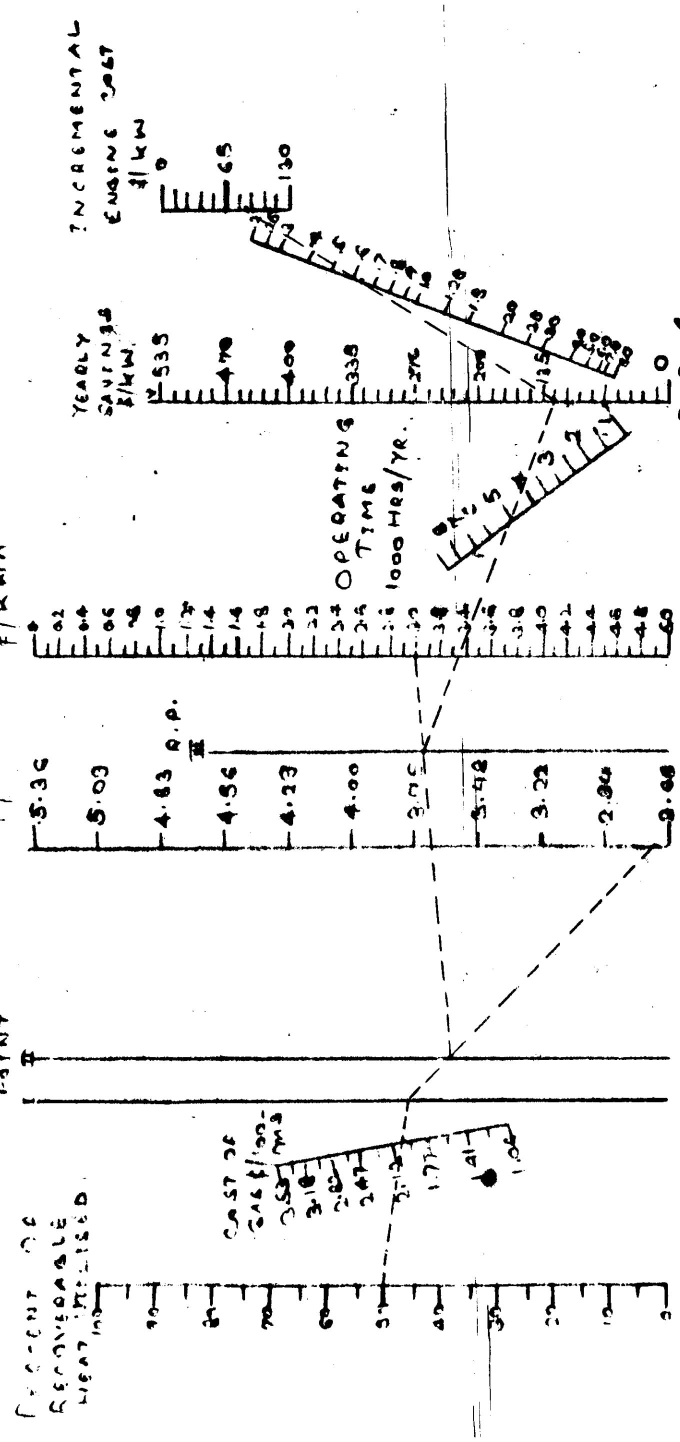


Fig. 1.2. Nomograph for Prime Mover Payout.

CALCULATION OF THE FUEL INJECTION SYSTEM IN DIESEL ENGINES FOR OPTIMUM INJECTION CHARACTERISTICS AND MINIMUM MECHANICAL STRESSES IN THE CAM SHAFT MECHANISM

Prof.Dr. AHMED HASSAN BAWADY
FACULTY OF ENGINEERING, AIN SHAMS UNIVERSITY, CAIRO, A.R.E.

ABSTRACT

The paper describes a mathematical model used to design the fuel injection system and evaluate the injection process in diesel engines. An accurate treatment of the injection process is developed by including certain factors which had been simplified in previous works. The given computer program is used to evaluate the effect of various operating parameters and dimensions of the injection system on the injection characteristics. A comparison between the theoretical results and the experimental measurements shows an acceptable agreement. A mathematical formula is proposed to calculate the position of the active stroke on the cam profile to minimise the mechanical stresses in the cam shaft mechanism.

NOMENCLATURE

- A_{con} -Cross sectional area of the sealing cone in the needle valve (m^2).
- A_d -Cross sectional area of delivery valve (m^2).
- A_n -Instantaneous area for the fuel flow between the needle valve and its seat (m^2).
- A_{ne} -Cross sectional area of the needle valve (m^2).
- A_p -Cross sectional area of the plunger (m^2).
- A_{pip} -Cross sectional area of the delivery pipe (m^2).
- C_p, C_i -Instantaneous plunger velocity (m/s).
- E -Bulk modulus (N/m^2).
- F_{do} -Initial tightening force for delivery valve spring (N).
- K_d - Spring stiffness of the delivery valve (N).
- M_d -Mass of the delivery valve (Kg).
- N -Cam shaft speed (r.p.m).
- P_c -Cylinder pressure or back pressure (bar).
- P_d -Pressure inside the delivery chamber (bar).
- P_f -Feeding pressure for the pump (bar).
- P_n -Pressure inside the needle chamber (bar).
- P_p -Pressure above the chamber (bar).
- U_f -Fuel velocity through the delivery pipe (m/s).
- V_d -Geometrical volume of the delivery chamber (m^3).

V_n -Geometrical volume of the injector chamber (m^3).
V_p -Volume of the fuel above the plunger (m^3).
Y_d -Lift of the delivery valve (m).
α -Coefficient of compressibility (m^2/N).
μ_o -Coefficient of discharge across the inlet port.
μ_d -Coefficient of discharge across the delivery valve.
μ_n -Coefficient of discharge across the cone of the needle.
γ_f -Specific weight of the fuel (N/m^3).

I-INTRODUCTION

It is well known that the design of the fuel injection system and the injection characteristics affect directly on the combustion process in the engine cylinders and concequently on the engine performance. Therefore,one of the most important proplems in developing the diesel engines is to select the optimum injection system to satisfy the engine requirements for a definite field of application. To minimise the experimental trials and save costs and effort , it is necessary to have an accurate mathematical model to calculate the fuel injection system and its characteristics. Investigations carried out in this field had generally an imperical character,and simplified the injection process,because of its complexity,which led to rough results(2,3,4,5).The present work tries to cover most of these simplifications and assumptions in order to approach the actual injection process and obtain reasoable accuracy of the results.To evaluate the proposed mathematical model a comparison between the theoretical results and the available experimental measurements is illustrated.

II- MATHIMATICAL ANALYSIS OF THE FUEL INJECTION SYSTEM

The basic equations(6)which define the fuel flow conditions at pump side,through the delivery pipe,and at the injector side are treated (fig.1). The finite difference method is used as a numerical method to solve these sets of equations.A computer program is designed for the given mathematical model using the IBM computer lab. in the Faculty of Engineering,Ain Shams University.

i-SIMULATION OF THE PUMP SIDE

The plunger displacement is calculated using a triangular form of the velocity diagram of the cam follower(fig.2). The instantaneous area of the fuel flow through the barrel ports is calculated according to plunger position(fig.3).

The basic equations of the fuel flow in the pump side are (neglecting the fuel leakage between the plunger and its barrel):

$$C_i A_p = \frac{V_p}{E}\frac{dP_p}{dt} + \mu_o A_o \sqrt{\frac{2g}{\gamma_f}(P_p - P_f)} + \mu_d A_d \sqrt{\frac{2g}{\gamma_f}(P_p - P_d)} + A_d \frac{dY_d}{dt} \quad (1)$$

$$A_d \frac{dY_d}{dt} + \mu_d A_d \sqrt{\frac{2g}{\gamma_f}(P_p - P_d)} = \frac{V_d}{E}\frac{dP_d}{dt} + U_f A_{pip} \quad (2)$$

$$M_d \frac{d^2 Y_d}{dt^2} + K_d Y_d = A_d (P_p - P_d) - F_{d_o} \quad (3)$$

ii-SIMULATION OF FLOW THROUGH THE DELIVERY PIPE

The flow through the delivery pipe is considered to be one--dimensional,unsteady,compressible flow. The delivery pipe is cosidered of costant diameter during the injection process i.e. the elastisity of the pipe is neglected.

The basic equations of fuel flow through the delivery pipe is obtained from Navier-Stokes equation of fluid motion:

$$\rho_f\left(\frac{\partial U}{\partial T}+U\frac{\partial U}{\partial x}\right)=-\frac{\partial P}{\partial x}+\mu\frac{\partial^2 U}{\partial x^2} \tag{4}$$

The inertia term $U\frac{\partial U}{\partial x}$ can be neglected without cosiderable error in case of fuel flow through the delivery pipe. The vis--cous term $\mu\frac{\partial^2 U}{\partial x^2}$ is treated using Weisback-Darcy equation,which can be put finally in the form:

$$\mu\frac{\partial^2 U}{\partial x^2}=\left(\frac{\partial P}{\partial x}\right)_{Losses}=\frac{4\,K\,D_{pipe}}{U}\,\frac{\rho_f U^2}{2\,D_{pipe}}=2\,\rho_f K U \tag{5}$$

The continuity equation for one-dimensional,unsteady,and compressible flow is:

$$\rho_f\frac{\partial U}{\partial x}+\frac{\partial P}{\partial T}=0 \tag{6}$$

Equations (5) and (6) are solved simaltaneously to calculate the instantaneous fuel velocity and pressure distribution along the delivery pipe.

iii-SIMULATION OF THE INJECTOR SIDE

The basic equations of the fuel flow at the injector side are:

$$U_{i,n}A_{pip}=\alpha V_n\frac{dP_n}{dt}+A_{ne}\frac{dz}{dt}+\mu_n A_n\sqrt{\frac{2g}{\gamma_f}(P_n-P_n')} \tag{7}$$

$$M_n\frac{d^2z}{dt^2}+K_n z=\left(A_{ne}-A_{con}\right)P_n+P_n' A_{con}-P_{air}A_{ne}-F_{on} \tag{8}$$

$$F_{on}+P_{air}A_n=P_{n_o}\left(A_{ne}-A_{con}\right)+P_c A_{con} \tag{9}$$

The pressure in the engine cylinder is assumed variable during the injection process (fig.4).

In addition to the above mensioned equations other important parameters are also taken into cosideration,namely,the friction inside the delivery pipe ,the voids which may be formed during the injection process,the delivery valve motion and,the variation of the fuel compressibility due to change of pressure.

III- DETERMINATION OF THE POSITION OF THE ACTIVE STROKE ON THE CAM PROFILE

To minimise the mechanical stresses in the cam shaft for given operating conditions of the fuel injection system the

plunger mean velocity during the injection process must be increased(1). This can be obtained by selecting the position of the actual stroke on the cam profile to give maximum plunger lift for a given injection duration φ_g. Analytical study for a triangular form of plunger speed gives the plunger displacement:

$$\Delta h = \frac{C_{max}}{2(\alpha_K - x)}\left[\left(-\alpha_K H^2 + 2H(\alpha_K - \varphi_g) - \alpha_K\right)x + 2\alpha_K\varphi_g - \varphi_g^2\right] \quad (10)$$

Where $H = \frac{\beta}{x}$

Integrating this equation for maximum Δh we get the eqn. for optimum angle of injection timming:

$$\beta = x\left(1 - \frac{\varphi_g}{\alpha_K}\right) \quad (11)$$

and the corresponding maximum active stroke

$$\Delta h_{max} = C_{max}\,\varphi_g\left(1 - \frac{\varphi_g}{2\alpha_K}\right) \quad (12)$$

To increase the plunger velocity for a given value of max. plunger lift, the plunger lift angle must be increased. This can be made to a certain limit:

$$\frac{\varphi_g}{\alpha_K} = 0.12 \div 0.4 \quad (13)$$

IV-EVALUATION OF THE PROPOSED THEORETICAL MODEL

A comparison is made between the theoretical results of the proposed computer program and the available experimental results (6). The results of such comparison are illustrated in fig.5,6. The calculations are carried out for a jerk pump type (C.A.V), Bosch (BpE 2B 70N 100 S536) with pintle nozzle injector type Bosch - DN 0S1).

The results show reasonable agreement between the theoretical calculations and the experimental measurements. Therefore, the proposed mathematical model can be recommended for the calculation of the fuel injection system system in diesel engines.

To investigate the effect of selecting the injection tim--ming by the proposed formula on the injection characteristics the computer program is used for the calculation of the fuel injection system under the following conditions:

Speed of rotation = 1000 (r.p.m)

N^o of trial	$\varphi_A = \varphi_B$	$\varphi_e = \alpha_K$	β
1	20	60	$\epsilon = 0$
2	30	60	$\epsilon = 0$
3	40	60	$\epsilon = 0$
4	20	60	From eqn. 11
5	30	60	" " "
6	40	60	" " "
7	0.4	From eqn. 13	" " "
88	0.5	" "	" " "
9	0.6	" "	" " "

Sample of such calculations are given in fig.(7) and tab.(1).

It is clear that the use of a symetrical cam profile (trials 2,5,8) gives good agreement and acceptable characteristics of

injection in comparison with the other shapes of the cam profiles. The application of the proposed formula to calculate the position of the active stroke on the cam lift curve gives acceptable results of injection characteristics in addition to less mechanical stresses in cam shaft.

V-CONCLUSION

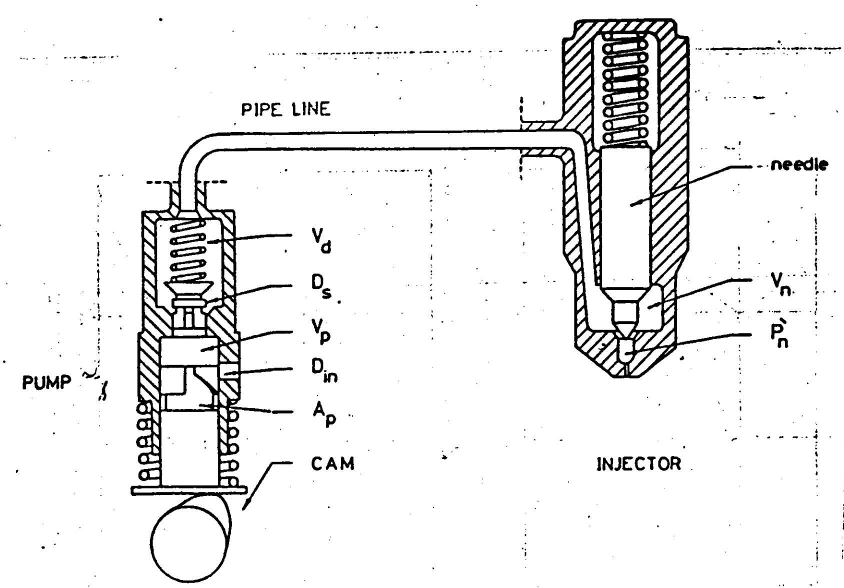
The proposed mathematical model shows a reasonable agree--ment with the experimental measurements. The given computer program can be recommended for developing the injection system and the combustion investigations of diesel engines as the instantaneous injection rate and injection pressure can be obtained. The use of the proposed formula to calculate the injec--tion timming gives acceptable results for the injection characteristics and minimum mechanical stresses in the cam shaft mechanism.

VI-REFERENCES

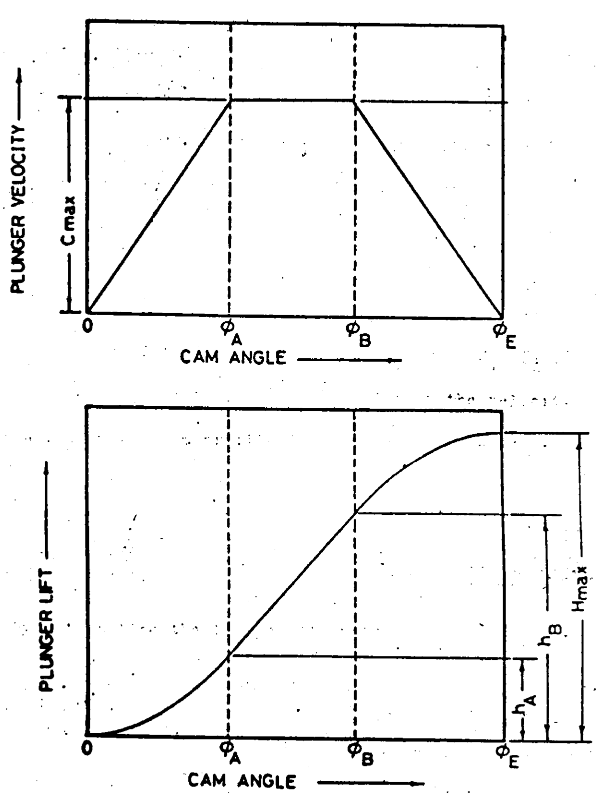
1- BAWADY A.H. "Theoretical and experimental methods of development fuel injection systems of diesel engines" Ph.D. Thesis,Polytechnic institute , Leningrad,1972.
2- Dejuhasz K.J. "Graphical analysis of trnsient pheno--mena in linear flow" Journal of Franklin,April,1936.
3- Giffen E. , Rowe A.W. "Pressure calculation for oil engine fuel injection system" Proc.I.M.E. Volume 141,1939.
4- Goyal M. " Modular approach to fuel injection system simulation" S.A.E. 1978,sec.1,No. 780162.
5- Knight B.E. "Fuel injection calculation" Proc.I.M.E. (A.D) part 1 1960-1961.
6- Safwat a.w. "Theoretical and experimental investigation of the fuel injection system for diesel engines" M.Sc. Thesis ,Menoufia university,1983.

Table 1 : Variation of injection parameters at different operating conditions.

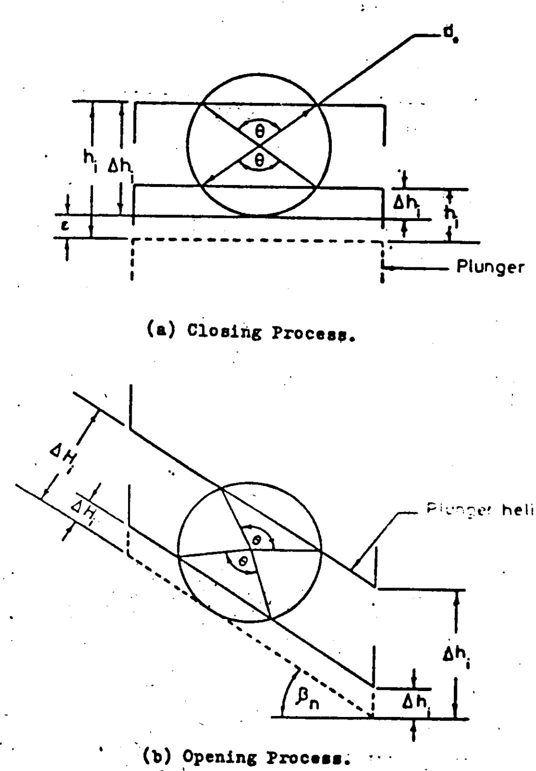
Trial No.	Res.pressure (bar)	Injection rate (m.g/cyc)	$P_{pmax.}$ (bar)	$P_{nmax.}$ (bar)
1	30.95	0.15716	210	240
2	54.32	0.15151	245	250
3	52.95	0.14831	170	210
4	30.95	0.15716	210	240
5	54.32	0.15151	245	250
6	52.95	0.14831	170	210
7	49.12	0.15700	400	550
8	62.33	0.14650	450	670
9	68.08	0.14560	450	550



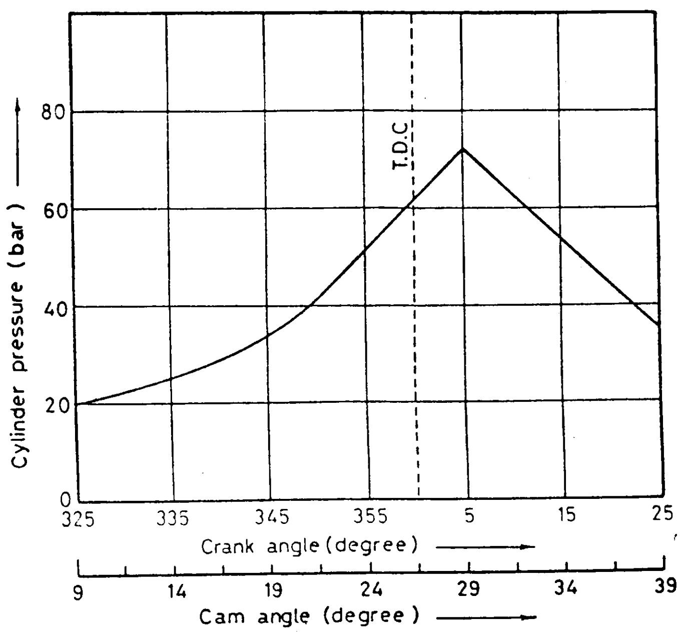
FIG(1) SCHEMATIC DIAGRAM OF INJECTION SYSTEM



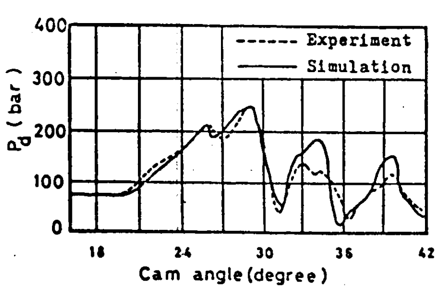
FIG(2) VELOCITY AND LIFT DIAGRAM FOR THE CAM.



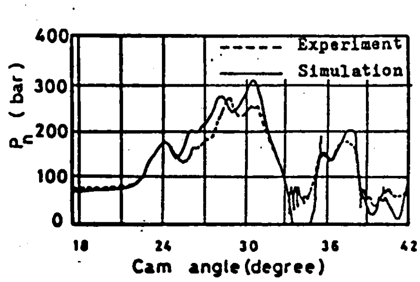
FIG(3) INSTANTANEOUS AREA OF INLET PORT THROUGH CLOSING AND OPENING PROCESS.



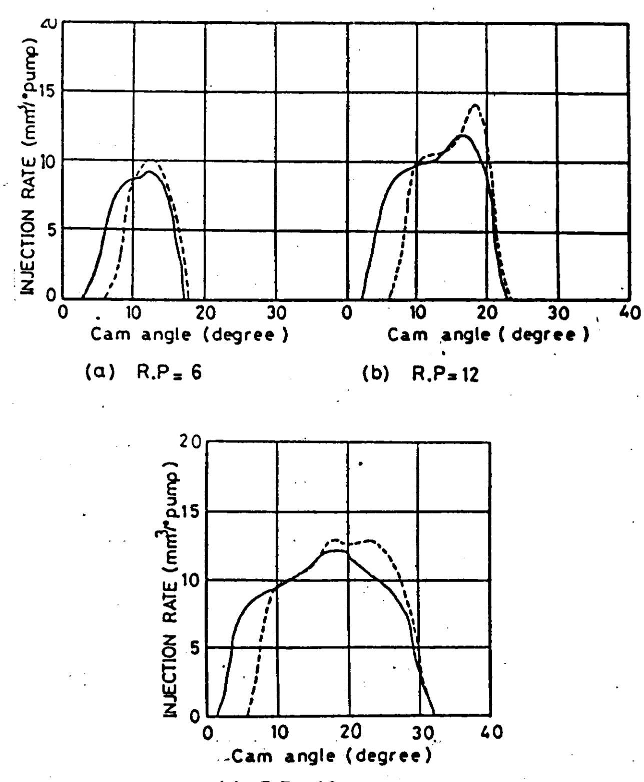
FIG(4) Variation Of Pressure Inside The Cylinder.



FIG(4.7) Comparison Between The Theoretical And Experimental Delivery Chamber Pressure.



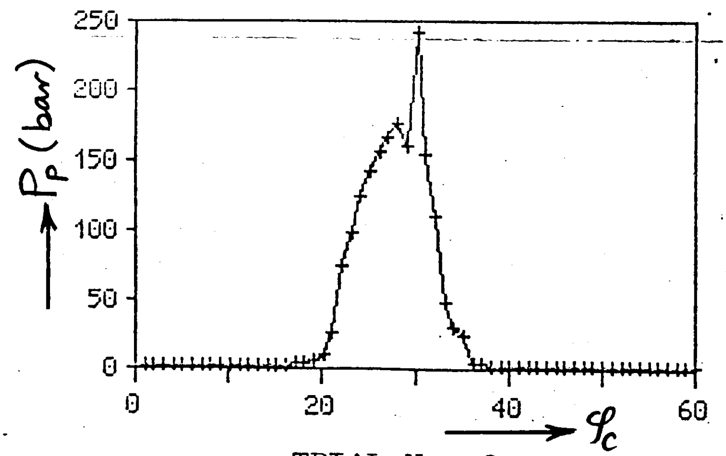
FIG(4 5) Comparison Between The Theoretical And Experimental Needle Chamber Pressure.



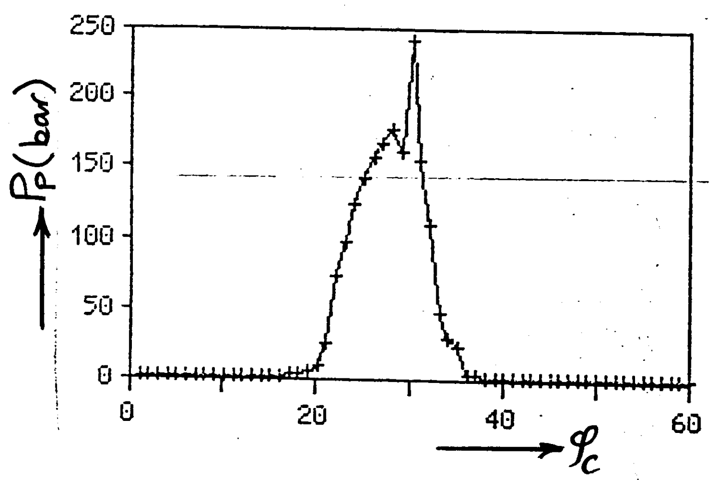
FIG(6) Comparison Between The Theoretical And Experimental Fuel Injection Rate(Pintle nozzle).

------ Experiment

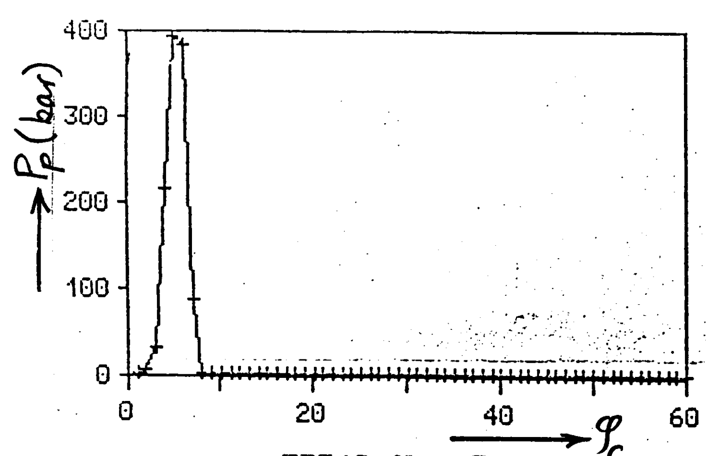
———— Simulation



TRIAL No. 2

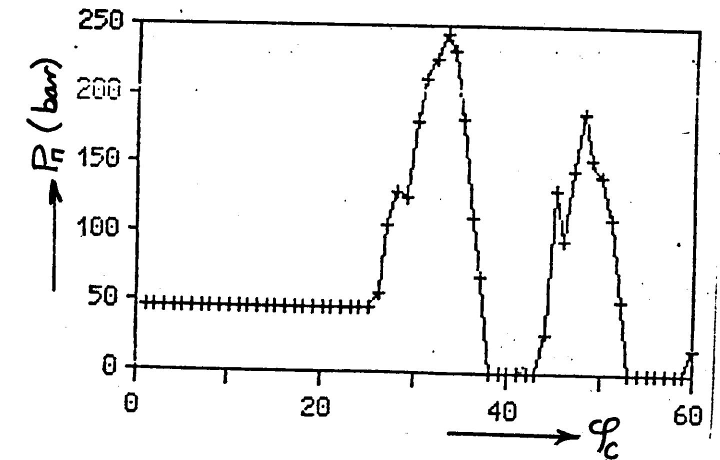


TRIAL No. 5

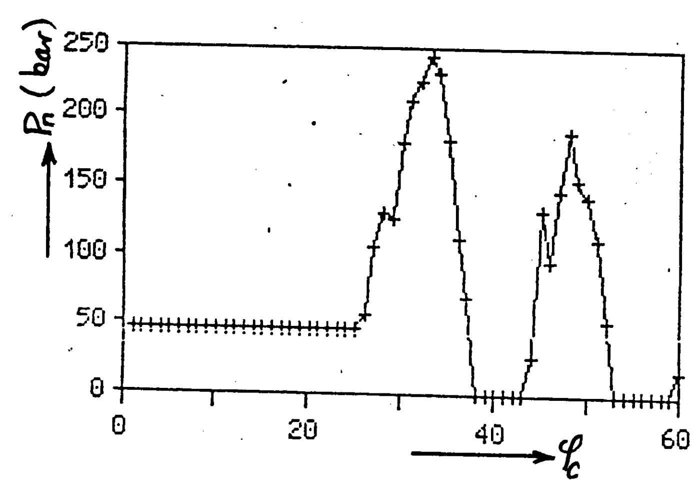


TRIAL No. 7

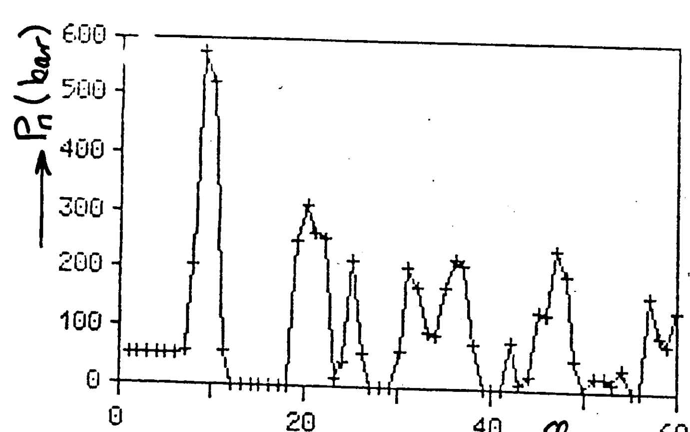
Fig.(7.a): Variation of pressure on the plunger during the injection process for different conditions. (calculated values)



TRIAL No. 2



TRIAL No. 5



TRIAL No. 7

Fig. (7.b): Variationof pressure inside the needle chamber.
(calculated values)

COMBINED CYCLE POWER PLANT IN HELLENIC ASPROPYRGOS REFINERY UPGRADING PROJECT

E. ZERVAKOS/G. KATOPODIS/M. MALLIARAKIS
Asprofos Engineering S. A.
El. Venizelou Ave. 50,
176 76 KALLITHEA, ATHENS
GREECE

ABSTRACT

A Combined Cycle Power plant, consisting of two gas turbine generators and one steam turbine generator (17 MW capacity each), has been included in the Modernization and Upgrading Project of the Hellenic Aspropyrgos Refinery (H.A.R.). Such a configuration of the refinery power plant has been selected after detailed studies during early engineering stage of the project. The main points that have been analyzed by those studies were the economics of the extra investment which was required (compared to other power plant schemes) and the operation of the whole refinery and every single process unit from safety and reliability point of view.

It is the intention of this paper to describe shortly the following:

- The importance of the electric power supply reliability for the safe operation of the complex.
- The configuration of the power plant and the refinery steam and fuel supply systems.
- The developed methodology for the combined cycle power plant feasibility study, its capacity definition and the evaluation of the various vendors proposals from the overall energy saving point of view.
- Some specific design features adopted to improve the safe and reliable operation of the whole complex.

2. H.A.R. UPGRADING PROJECT

Hellenic Aspropyrgos Refinery (H.A.R.) is a state owned refinery having a capacity of 120000 Barrels per stream day. The configuration of H.A.R. up to 1987 was of the hydroskimming type, i.e. including only crude distillation (two units), catalytic reforming of straight run naphtha and hydrodesulphurization of gasoil distillate. This scheme resulted in a high production of low value fuel oil. In 1982 Greek Government decided to proceed with the modernization of H.A.R. by adding conversion units. The H.A.R. upgrading project involves the addition of new process units with the purpose of converting a substantial portion of the fuel oil into more valuable distillate products. After the completion of the upgrading project, H.A.R. operates in a competitive and active mode both within Greece and

abroad. The following new process units were included in the project.

	Design Capacity (BPSD)
Vacuum Distillation	50000
Visbreaker	23200
VGO HDS/Low Pressure Hydrocracker	27400
Fluid Catalytic Cracker	25000
FCC Gasoline Sweetening	17000
LPG Sweetening	10300
Catalytic Reformer (with continuous catalyst regeneration)	21500
Light Naphtha Isomerization	7500
MTBE Unit	190 Tons/day
C3/C4 Dimerization	305 Tons/day
MEA Treating	185,5 Tons H2S/day
Sulphur Recovery Unit	200 Tons S/day
Sour Water Stripper	3050 Tons Water/day
Hydrogen Production	9.1 MMSCFD

The addition of the above new process units required revamp works of the existing process and utility units and offsite facilities plus some new utility units, some new offsite facilities and the required interconnecting lines.

H.A.R. upgrading project has been executed under the project management of Asprofos Engineering, a company initially owned partly by H.A.R. (51%) and FWI (49%) and now owned completely by H.A.R.

2.1 Critical Loads

During early engineering stages of the project, steam and power balances (plus the other utilities balances) of the whole complex have been prepared for various operating schemes and contingencies, in order to define the best power plant configuration and the sizes of the various power plant facilities and equipment. One of the most important factors involved in those studies was the requirement to have a safe shutdown of the refinery units in case of failure of the external power supply network of Public Power Corporation (P.P.C.). In this specific contingency while the drivers required for the normal operation of the units (normal loads) are lost, some other drivers and loads, that are absolutely necessary for the safe shut down of the units (critical loads), have to remain in operation or have to be started some seconds after the event of power failure. From the above definition of the critical loads it is evident how much important it is the requirement to have power supply for them under any contingency, especially in case of PPC network failure.

In the critical loads group of the refinery the following services, among the others, are included :

- Boilers air and flue gas fans
- Boilers fuel oil pumps
- Boilers feed water pumps
- Instrument air compressors
- Cooling water pumps
- Cooling tower fans
- Demineralized water pumps to deaerators
- Some flare system pumps

- Some main towers reflux pumps
- Some top air coolers of the towers
- Some towers bottom pumps
- Some hydrogen recirculation compressors in units having reactors with catalysts
- Some drivers which are used to decrease the flare load during power failure
- Some other critical services depending on the various services in the process and utilities units i.e. cooling or flushing or emptying of some equipment etc.

From the above list it is clear that the number of the refinery critical loads is high enough. The first approach for the solution of the problem was the conventional one, i.e. all the critical drivers (main or spare) to be back pressure steam turbines in order not to be lost at the moment of the event or to be started some seconds later. This solution resulted in a very big amount of high and medium pressure steam requirements and thus in high investment for new utility boilers installation. In addition to the above the H.P. steam required during the power failure was much higher than the H.P. steam required for the normal operation of the whole refinery, a moment before the event. Because of that situation utility boilers had to increase their steam production from 30 or 40% up to 90 or 100% in a very short time (less than one and a half minute) which was not technically possible to be implemented in the design of either the new or the existing boilers. At the same time, due to the very high production of low pressure steam from the back pressure turbine drivers, a lot of L.P. steam had to be vented to the atmosphere creating a lot of noise and increasing the confusion of the operators at this moment very much.

Some alternative solutions were studied afterwards in order to overcome the above two problems but without success. For example the case with the big critical machinery (i.e. some compressors) driven by condensing turbines were rejected because the operating cost increase of the whole complex was significant.

2.2 Power Plant Configuration Alternatives

Because of the above problems another solution for the configuration of the system has been studied which was the following :

- The critical drivers which are not permitted to be lost even for one second have been selected to be back pressure turbines (i.e. air fans of the boilers, hydrogen recirculation services, other process services etc.).
- The critical drivers, which are allowed to be lost for a few seconds and then to be restarted, have been specified to be electric motors which, in case of PPC failure, will be supplied by the electric power produced by a refinery steam turbogenerator which had to be installed for that purpose.
- The electrical system of the refinery (i.e. substations, distribution network, motors, control and safety devices etc.) plus the utilities systems of the refinery (steam, instrument air, cooling water etc.) have to be designed in such a way so that the refinery steam turbogenerator will remain in operation in case of external PPC network failure.
- Two steam turbogenerators (one main, one 100% spare) have to be installed in order not to shut down the refinery in case that the main steam turbogenerator is out of operation. This is because in case of power failure, an internal steam turbogenerator must be always available so that it will keep the critical loads of the refinery in operation in order to have

a safe shut down of the refinery.

The above solution had been analyzed in details from all its possible options and it was decided that it could be implemented in the H.A.R. upgrading project.

Steam and power (and the other utilities) balances have been prepared for a lot of operating cases of the refinery and for other contingencies, considering the new power plant configuration. It was proved that all the possible design problems could be solved during the process and detailed engineering of the relevant systems. The main disadvantages of this configuration were :

(i) The point that every time there is a problem in the external PPC network (undervoltage, underfrequency etc.) refinery units will have to be shut down.

(ii) The uncentainty whether the electrical design of the system can verify that under all the possible power failure contingencies the internal steam turbogenerators will remain in operation in order to run the critical loads.

(iii) The extra investment for a 100% spare steam turbogenerator of about 12 MW.

At this stage of the design, Asprofos started to analyse the installation of a power plant able to cover the total power request of the refinery, consisting of two gas turbine generators and one steam turbogenerator. Having this configuration of power plant, the disadvantages of the solution with the 2 steam turbogenerators were eliminated.

Of course it was evident that basic and detailed engineering of the related systems had to be performed in such a way so that it will be proved that the three (or the operating at that moment) internal refinery generators will remain in operation in case of external PPC failure.

Economic analysis of the combined cycle power plant in the H.A.R. Upgrading Project proved that such a configuration was also attractive from pure economics point of view. Preliminary calculations concluded that the pay-out period of the required extra investment (over the investment of competitive power plant schemes) was less than 2.5 years due to the decrease of the refinery operating cost, without considering the savings from the decreased number of the refinery shut downs due to external PPC network problems.

For the above reasons the combined cycle power plant consisting of two (2) gas turbine generators and one steam turbogenerator, 17 MW capacity each, have been selected for the H.A.R. Upgrading Project as the most efficient from safety and pure economics point of view.

3. DESCRIPTION OF THE H.A.R. POWER PLANT AND FUELS SYSTEM

3.1 H.A.R. Power Plant

Combined cycle power plant had to be designed considering the following points related with the whole complex requirements :

(i) Power plant has to produce electric power in order to keep all the refinery units in operation without any power import from the external PPC network. Actually during normal operation the three internal generators will operate in parallel with external PPC network in order to secure power

supply in case of one internal generator failure. For this reason 0.5-1.5 MW will be always imported from PPC network, while frequency and voltage of refinery network will be controlled by PPC network.

(ii) H.P. Steam, M.P. Steam and L.P. Steam to process, utilities and offsites units are to be supplied by the power plant at various operating modes of the refinery including some emergency situations.

(iii) Boiler Feed Water for steam production inside process units is supplied also by the power plant.

(iv) Condensates at various pressure and temperature levels are returned back to power plant where flashing is taking place to produce steam at lower pressure in order to save energy.

(v) The existing equipment has to be reutilized at the maximum extent.

(vi) The whole power plant and the related equipment (i.e. steam turbine drivers of the complex, steam generators inside process units etc.) have to be optimized from energy point of view.

(vii) Design has to be performed with high enough flexibility in order not to create any problem to the process units in case of malfunction of one part of the power plant.

Based on the above, the configuration shown in the simplified schematic power plant diagram (Fig. 1) was finally selected which is consisted of the following main equipment :

(i) Two gas turbine generators 17 MW each (20 MVA) with two waste heat boilers (one per each gas turbine) producing H.P. Steam and L.P. Steam to the refinery networks.

(ii) One steam turbine generator 17 MW (20 MVA) with one extraction section producing L.P. Steam and one condensation section. Extraction section of the turbine has been designed in order to produce the L.P. Steam required by the process units while the condensation section is used for emergency situations such as power failure while one or two gas turbines are out of operation or H.P. steam surplus in the refinery network.

(iii) Existing refinery boilers (no new boiler has been installed). They produce the extra H.P. steam which is required to cover the refinery steam balance.

(iv) Let down stations

M.P. steam to process units is produced through a let down and desuperheating station. M.P. steam flow through this let down is kept minimum by operating the required H.P.S. to M.P.S. back pressure steam turbines inside process and utilities units. A let down and desuperheating station M.P.S. to L.P.S. is also installed to produce L.P.S. for the refinery units in case steam turbogenerator is out of operation.

(v) All the other equipment necessary for the operation of the power plant such as deaerators, condensate flash and collection drums, blowdown flash drums, condensate deoiling and polishing units etc.

Such an arrangement allowed H.A.R. to proceed with the implementation of the power plant in two stages due to budget limitations and to other investment policy reasons. Actually the whole power plant except gas turbines is in operation since end of 1986 while the expected date of gas turbines start up is June 1989.

3.2 Fuel Oil and Fuel Gas Systems

Fuel gas is produced by refinery units at various pressure levels. Fuel gas streams produced at a pressure higher than 23 barg are collected in the high pressure fuel gas header in order to feed directly the gas

turbines. All the other fuel gas streams are collected in the low pressure fuel gas header. A part of the L.P. fuel gas is compressed at 23 barg and sent to the H.P. fuel gas system since H.P. fuel gas is not enough to cover gas turbines maximum capacity requirements. The rest of the L.P. fuel gas is burnt in the refinery process heaters.

Refinery heaters are equipped with dual fuel gas and fuel oil firing systems. Two types of fuel oil is burnt in the refinery heaters. Fuel oil type 1 is a normal 3500 Redwood I fuel and is used into the old refinery units heaters and the utility boilers. Fuel oil type 2 is the bottom product of the visbreaker unit (visbroken residue) and is burnt in the new units heaters without being fluxed by light distillates. Fuel oil type 2 value is about 75% of the fuel oil type 1 value.

Such an arrangement of the fuel gas and fuel oil systems offers an advantage to the gas turbines installation because the fuel gas which is used to run gas turbines will be taken from the new refinery heaters where equivalent (from heating value point of view) fuel oil type 2 will have to be burnt in order to keep the process heat requirement. Considering the overall refinery fuel balance, gas turbines operation results in an increase of the consumption of the low value fuel oil type 2.

4. EVALUATION OF THE REFINERY OPERATING COST SAVING AFTER THE GAS TURBINES INSTALLATION -FEASIBILITY STUDY

For the feasibility study of the gas turbines installation project, the main point was the determination of the total refinery variable operating cost saving due to the operation of the gas turbines. Refinery steam, power, water, condensates and fuels balances have been prepared without taking into account the effect of the power plant operation on those balances.

For each one of the two power plant configurations under comparison i.e. the combined cycle power plant as it was described and the power plant without the two gas turbines, utilizing an L.P. program the optimum operating points of the various main equipment (i.e. gas turbines, boilers, steam turbogenerator) were found. The operation of the power plant at these points results in the minimum operating cost for the refinery.

Considering that steam, fuel gas and power produced by the refinery generators are internal streams of the refinery, the objective function of the program which had to be minimized was the cost of the imported from PPC power plus the cost of the fuel oil type 1 plus the cost of the fuel oil type 2 plus the cost of the other utilities consumed inside the power plant (see Fig. 2). This cost does not represent the total refinery operating cost but a part of it which is affected by the configuration of the power plant. Because of that, the difference on the value of the two objective functions for two power plant configurations represents the refinery operating cost saving after the gas turbines installation.

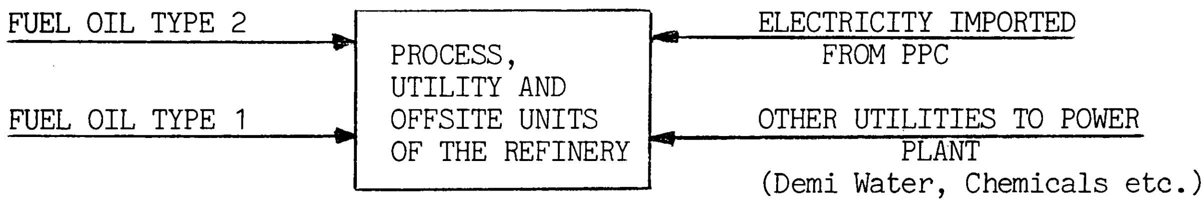


FIG. 2

The constraints (equations) of the L.P. program represent the power plant mass, heat and power balance which simulate the power plant operation (fuels consumption of the heaters is also included), according to the two different configurations.

At the time of execution of the feasibility study, the performance of all the equipment involved in the power plant operation (i.e. boilers, steam turbogenerator, heaters etc.), except gas turbines, was known.

Data for the performance of the gas turbines were taken from various gas turbines vendors general information. Feasibility study has been completed taking into account, in addition to the decrease of the variable operating cost of the refinery, the effect of the gas turbines on the fixed operating cost of the refinery (increase) i.e. capital, maintainance, insurance and extra personnel cost. In addition to the above a sensitivity analysis has been performed considering the most probable future prices of the crude oil (and hence the fuel oil type 2) and the imported power from PPC. The study concluded that a pay-out period of 2.5 years for the extra investment was expected.

At this stage of the study the power production of the three internal generators has been calculated at various normal or emergency operating schemes of the refinery. This production was 9-12 MW for the steam turbogenerator and 12-15 MW for each of the gas turbine generators. The design capacity of the three generators of 20 MVA (about 17 MW) was selected considering, in addition to the above, the following points :

- the possible future expansion of the refinery
- the best configuration of the refinery electrical network for minimum investment and simple design and operation of the network.

The same procedure of the feasibility study has been followed during the bid period for the evaluation of the various gas turbines vendors offers from operating cost saving point of view. For the evaluation of each gas turbine, at this stage of the study, the guaranteed figures for the performance of the gas turbines (i.e. efficiency, fuel gas consumption, steam production, utilities consumption) have been used. During the evaluation, the results of the feasibility study have been verified having slightly increased pay-out periods of about 3 to 3.5 years for the various offers.

The optimum operating point (power production) for each type of the offered gas turbines was different. At the point of minimum operating cost the different performance of the gas turbines from efficiency and steam production point of view resulted in different power production from steam turbogenerator. This resulted in different power production from the gas turbines in order the sum of internal power production to cover the refinery demand.

It is noted also that due to the different winter balance of the refinery compared to the summer balance and to the gas turbine performance change with the ambient temperature, actually two studies have been performed, winter and summer case, and an average weighted value has been used for the evaluation study.

For the final selection of the successful bidder, in addition to the results of the operating cost saving, other important factors such as reliability and availability factors, client requirements for the machinery, instrumentation, electrical portion of the offers, machine references etc, have been also taken into account.

5. OTHER DESIGN FEATURES

One of the main points, that the design of the refinery electrical network had to guarantee, was the requirement the internal generator(s) to remain in operation in case of failure of the external power supply or one of the internal generators or fault inside the electrical network (buses etc.). For that purpose specific design features have been adopted while numerous studies have been performed in order to secure the above requirement.

An electrical load shedding system has been provided with the scope of :

- preventing the collapse of the electrical system, which would cause the deenergization of vital services
- minimizing the disturbance to the electrical system and to the electrical users in case of a disturbance or outage of the supply sources.

In case of loss of one or more power sources the normal loads of the refinery shall be shed (reduced) in accordance with the availability of sources, taking into account their capability to supply additional loads, within the limits imposed by the acceptable voltage and frequency variations.

Reacceleration facilities of the electrical motors have been provided in order to resume automatically and in a short time the normal operation of the refinery units, not affected by the load shedding system, following an upset of the normal operation caused by a voltage dip or a momentary power failure or a "permanent" failure of one or more of the power supply sources. The design of the system includes all the necessary facilities to automatically restart and reaccelerate all the motors of the refinery units, in a certain sequence and time, according to their criticallity.

A lot of studies have been performed such as electrical network stability studies, reacceleration capability for voltage drops and overcurrent in order to define the acceptable reacceleration sequence under various senaria of contingencies, short circuit calculations, load flow calculations etc.

In addition to the above a steam load shedding system has been installed in order to allow the working boilers to cover the steam requirements during the various emergencies. The steam shedding system will act cutting out all the steam loads which are not essential during the emergencies.

6. CONCLUSIONS

This presentation demonstrated very briefly that a combined cycle power plant was the most attractive power plant configuration for the Hellenic Aspropyrgos Refinery upgrading project. The developed methodolcgy for the evaluation of the variable operating cost saving of the refinery was not based on any new or advanced knowledge but it is believed that it solves the problem in a systematic way without taking into account information that can create confusion such as steam prices and internal generatcrs produced power price. The same methodology can be utilized to solve similar problems such as the optimum power plant configuration, the optimum steam pressure and temperature levels and the evaluation of the various vendors offers for the main power plant equipment.

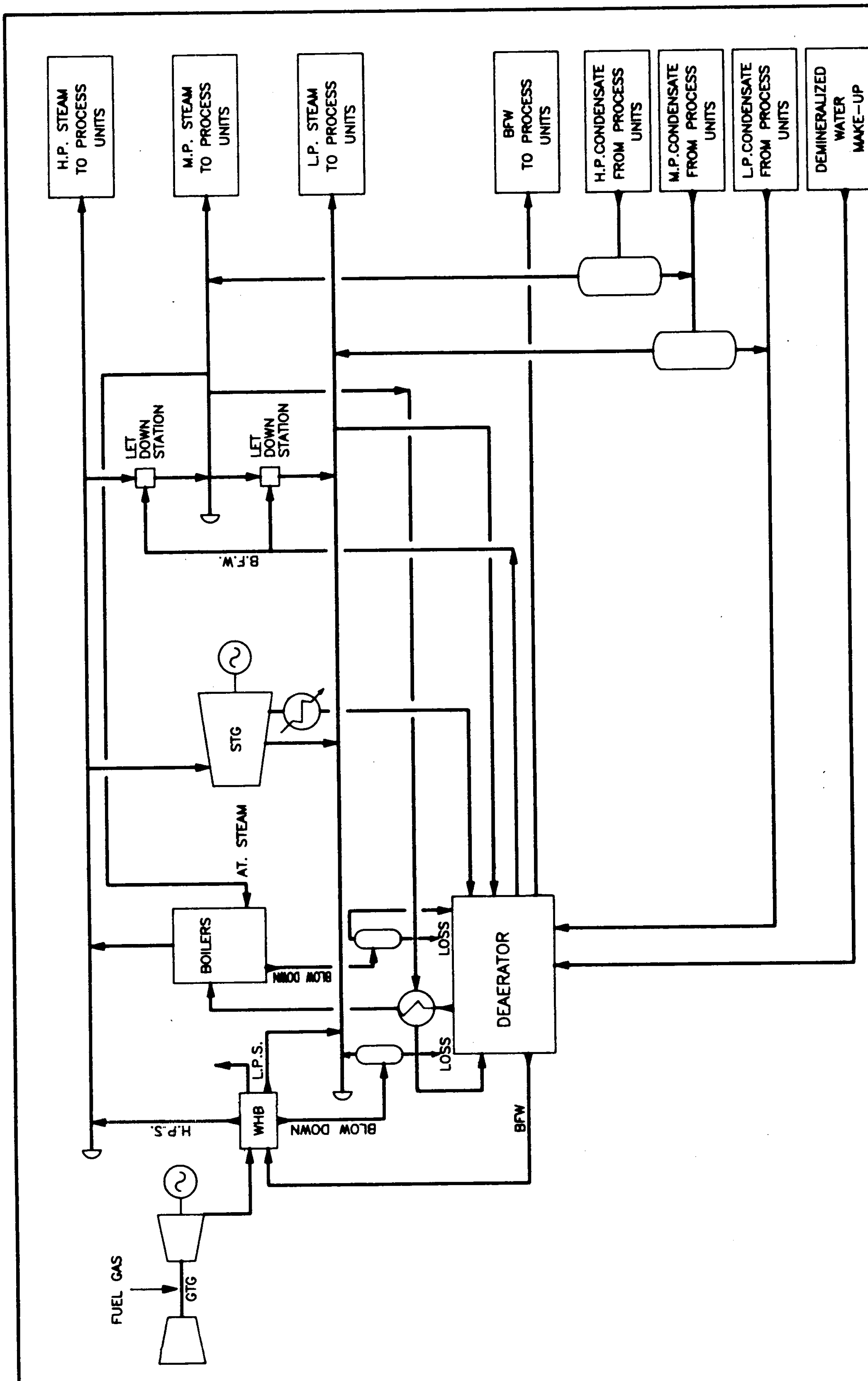


FIGURE 1
Simplified schematic
power plant configuration

THE LATEST DEVELPMENTS IN MARINE DIESEL ENGINES

Hamed El-Hamza and Giuma El-Fallah

University of Al-Fateh
Marine Engineering Department
Tripoli, Libya

ABSTRACT

Before the petroleum crisis in 1973, the specific fuel consumption had not been given the first priority by the marine diesel engine builders in the design process, since the oil prices were low, and the fuel cost percentage of the total operating cost of a ship was also very low. After the 1973 crisis the fuel cost percentage jumped to a range of 30% to 60% of the total running cost, depending on the type of ship. The marine diesel engine builders have adopted two approaches for operation cost reduction. The first approach is to burn cheaper fuel of an inferior quality, secondly is to reduce the specific fuel consumption. The problems involved with the use of heavy fuels are described in this paper. These problems may be categorized as:

i - Storage and handling, which create problems in pumping and injection of the fuel due to its high viscosity and the presence of sludge, also there is a difficulty of separating the water from the heavy fuel, as its specific gravity approaches unity.

ii - Combustion quality and burnability. The most undesirable feature of the heavy fuel is its poor combustion characteristic. Other problems involved are the engine knocking, after burning, uneven burning, variation in ignition delay and steeper ignition pressure gradient.

iii- Contaminants, resulting in corrosion and/or damage to engine components. The most dangerous contaminants in the heavy fuel are: sulphur, vanadium and sodium. The sulphur oxides are dangerous at exhaust temperatures less than 150 C, while vanadium sodium oxides are dangerous at very high temperatures. The sulphur may affect the crank case of the engine, while vanadium and sodium components affect the piston face and combustion chamber parts.

Recent development in the area of specific fuel consumption reduction are presented in this paper. This presentation is concerned with:

a - The use of the residual fuel in cross-head engines, utilizing the maximum firing pressure and waste heat recovery.

b - The improvement in the thermal efficiency of the marine diesel engines where the efficiency is advancing to 55% and SFOC approaching 120 g/bhp.hr.

"The marine Diesel Engine and its environment have changed more in the last ten years than in the previous three decades", (1).

The driving force which was behind those changes in marine diesels was the fuel price.

After the energy crisis of 1973 the energy prices increased ten-folds between 1973 and 1979, during which period the price of a ton of fuel oil increased from US $ 20 to US $ 200. (2).

Today the total engine costs may approach 50% of the ships total operating expenses (2).

The total engine costs may be distributed as follows:

- Fuel oil................................	73%
- Capital (Depriciation and interest) ...	19%
- Maintenance	4%
- Lubricating oil	4%

The most important modifications took place in the marine diesels design, which result in reduction of the specific fuel oil consumption (SFOL), may be summarized in the following:

1) Increasing Stroke/Bore Ratio:

Before the big jump of the fuel prices in 1973, a generation of large bore marine diesels was evoluted. Examples of such large bore engines are:

- B & W, type K98F
- Sulzer, type RD105
- Fiat, type 1060S

The basis behind the evolution of that generation of engines was that the increase in cylinder bore, leads to raise the power proportionately to a large amount, as:

$$\text{Power} \quad D^2$$

There are many limitations to restrict the increasing of the bore to a large limit, such as, the cylinder pitch, the diameter of the crankshaft, and the rules of the classification societies.

Moreover, from considerations of combustion chamber design, it is found that the stroke to bore ratio of (1.5) gives the best results for four-stroke engines, and a slightly higher ratio for two-stroke engines (3).

After the energy crisis, the trend was toward a longer stroke engines, with uniflow-scavenging.

In 1976, Sulzer introduced the RTA series of super long stroke, employs stroke to bore ratio of around 3:1.

In service now the ultra long stroke S80 MC, S70 MC, S60 MC and S50 MC built by MAN - B & W with a stroke/bore of 3.82:1.

The main merits of the longer stroke engines may be summarized in the following:

a) Improvement of the thermal efficiency of the engine, resulting from the efficient uniflow-Scavenging, which reduces the amount of residual gases in the cylinder and, improves the combustion efficiency.

As the scavenge air enters the cylinder from the bottom and sweeps it upto the top, the thermal load of the cylinder is reduced, more than in case of loop-scavenging.

Moreover, the scavenging efficiency is improved further, when using what is called CSS - System (Controlled Swirl Scavenging).

This system (CSS) has been adopted in for the (UEC-L) type engines of Mitsubishi.

In this system, the inlet angle of the scaveng ports is arranged so as to give, a strong rotation at its upper part, and the stream towards the cylinder center at its lower part, which resulted in better scavenging of residual gases near the cylinder wall and, the cylinder center. This system reduces the (SFOC) of the (L-type) engines considerably as shown in Fig. (1).

b) The longer stroke engine reduces the shaft speed, without reducing the mean piston speed (mps), a feature which enable both of the engine and, the propeller to work near its efficient limit, i.e. improving the propulsive efficiency by reducing the propeller speed, and enabling to use larger propeller.

An example of this case, is the improvement of the propeller efficiency by 5% when the stroke of the (L-GF) series of B & W engines was increased by 22% over the stroke of the (K-GF) series, resulted in 18% reduction of shaft speed and, leading to improvement of thermal efficiency by 7% as a result of combining the longer stroke with constant pressure turbocharging. From the point of view of better combustion, the longer stroke with slower speed of revolutions gives an advantage to burn heavy fuel in the engine, as much time is available for combustion to take place. The relation between the stroke to bore

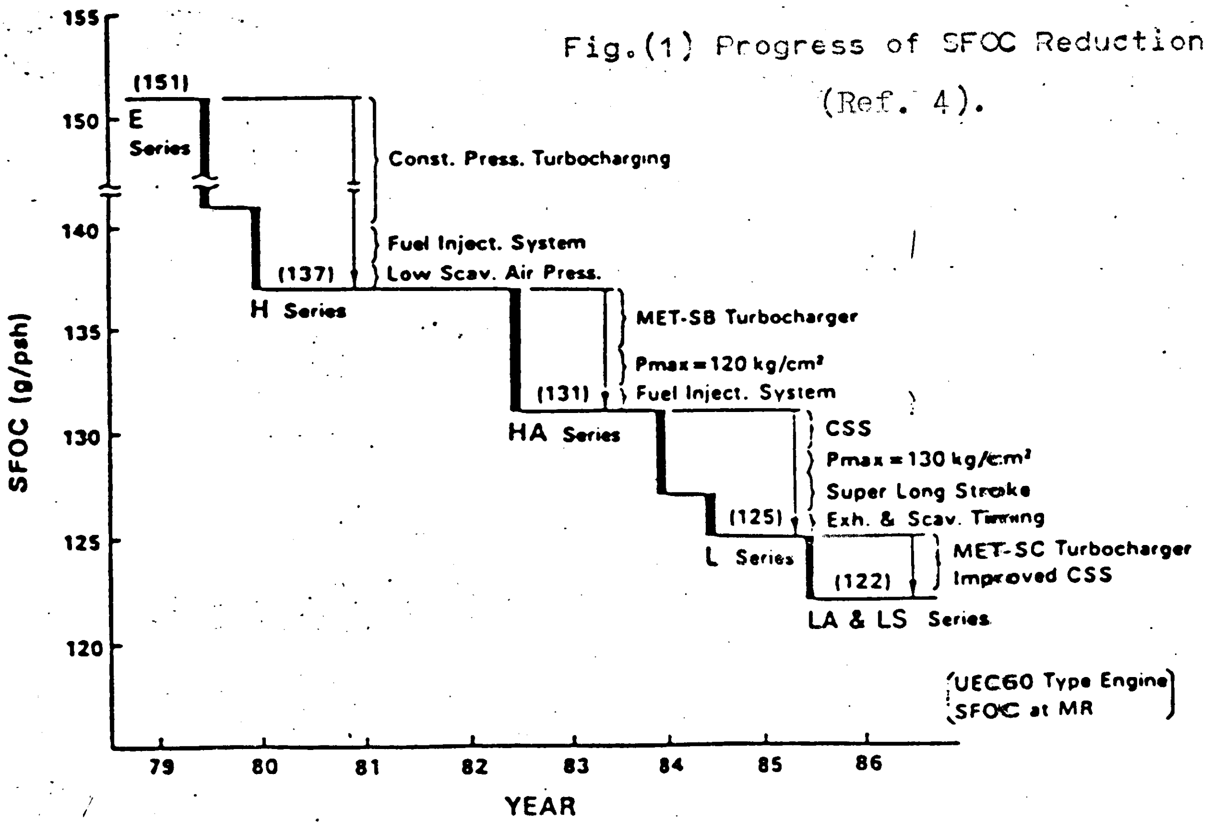


Fig.(1) Progress of SFOC Reduction.
(Ref. 4).

ratio and, the (SFOC) may be better explained by Fig. (2).

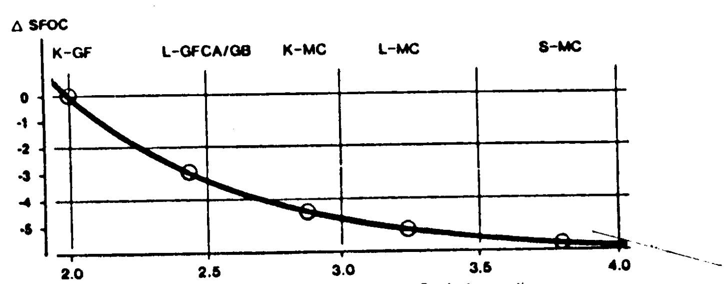


Fig. (2) Effect of Stroke/Bore on (SFOC).
(From Ref.7).

2) Increasing the maximum combustion pressure:

The maximum combustion pressure is supposed to be shock load on the engine components affected by the combustion pressure. As the fuel price was very cheap, compared with the initial first cost of the engine, the designers were neglecting the use of maximum combustion pressure to improve the thermal efficiency of the engine, as this leads to a massive engine.

After the energy crisis, the maximum combustion pressure was raised to a higher levels, especially after 1979, as shown in Fig. (3).

In some medium speed diesels the maximum combusion pressure approach (153) bars, as is the case in medium speed engine, S.E.M.T - Pielstick PC-20E.

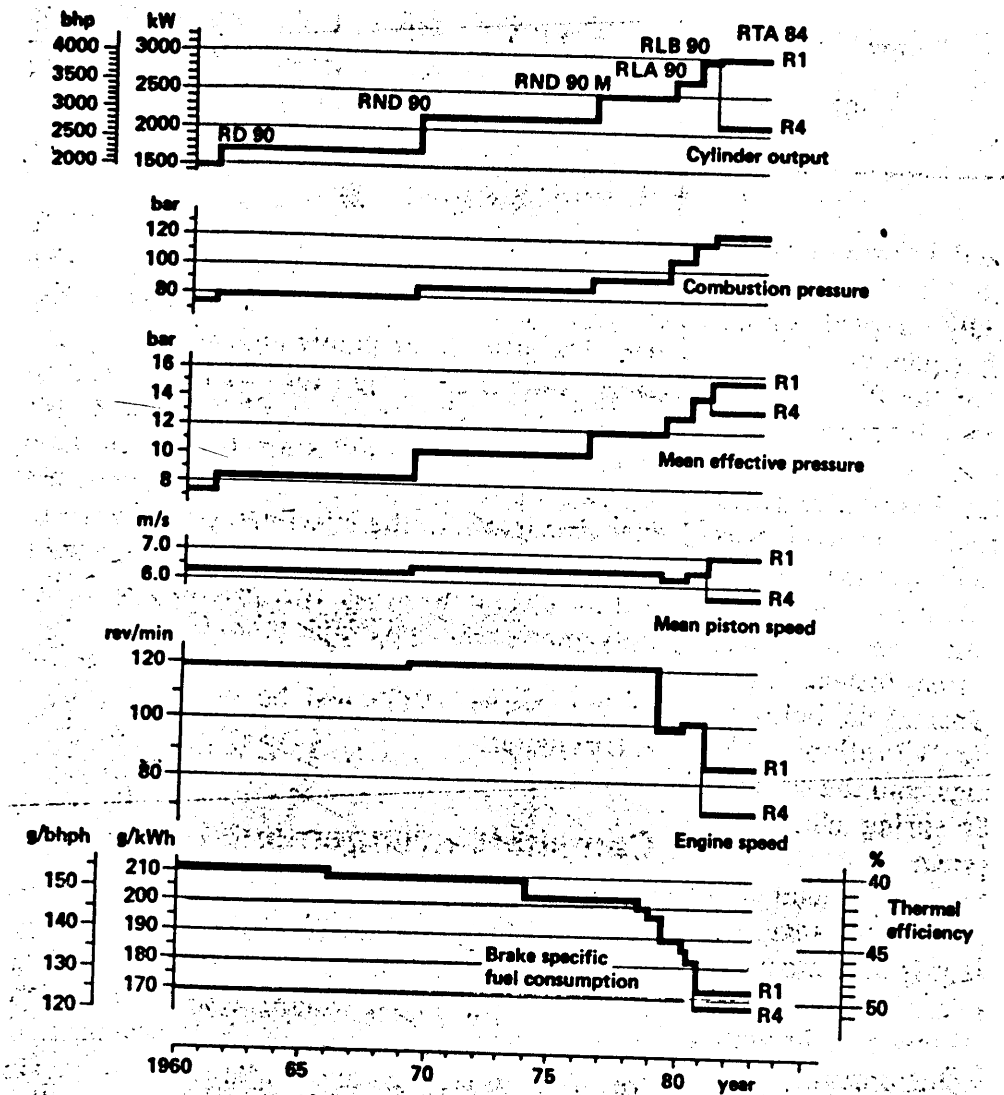


Fig.(3) Performance parameters of Sulzer's R series of low speed engines since 1960. Ample component design margins have been allowed to accommodate the higher mechanical loading (Ref. 5).

Accompanied with the increase of maximum combustion pressure, the mean effective pressure (Pe) is increased also, as shown in the same figure (Fig. 3), which means that the output of the engine is increased.

The reduction in (SFOC) with the increase of the ratio of maximum combustion pressure (P_{max}) to (P_e) is well explained in Fig. (4).

In order to avoid the shock load on the engine resulting from raising the (P_{max}) the bore of the cylinder is reduced, i.e. the shock force acting on the engine components (such as piston, piston rod, connecting rod, crank-shaft and bearings) is reduced. That is why the super long stroke engines have a smaller bores, compared with their preceeding generation of engines.

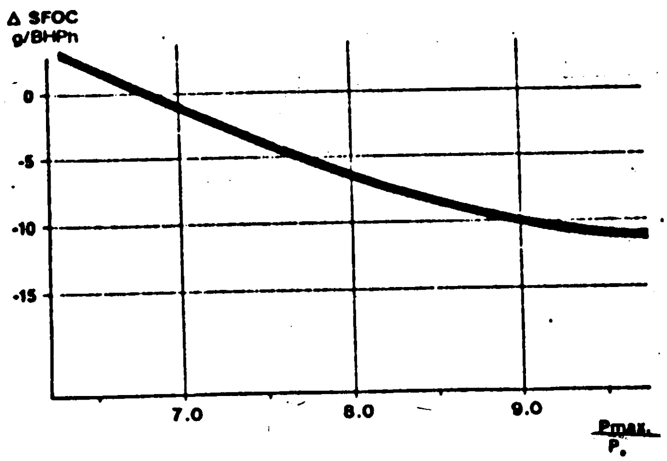


Fig. (4) Process parameters influencing specific fuel oil consumption (Ref. 7).

One of the latest uses of (P_{max}) practice is the case of (Wartsila Vasa 46), where the (P_{max}) approaches (200 bars). with (P_e) 30 bar, while (SFOC) is reduced to 165 g/Kw.h., without affecting the operational reliability and the output/weight ratio.

3) Using efficient turbo-chargers:

For marine diesels there are four builders supplying all the turbocharger installed on marine engines: (1).

- Brown Boveri
- Napier
- Mitsubishi, and
- MAN.

The trend of today is toward using non-cooled turbochargers, in order to raise the exhaust gas exit temperature for waste heat recovery system, to generate steam for electricity production. The temperature at the turbocharger outlet may be raised 10°C to 15°C when using uncooled turbochargers compared with water cooled turbochargers, which means improving the usable waste heat recovery by about 10%.

The turbochargers of Brown Boveri type VTR 4A approach an efficiency between 68% and 71% at compressor pressure ratio between 1.5 and 3.5, leading to improvement in (SFOC).

For electricity production purposes, the exhaust gas temperature in the boiler outlet is to be as low as possible, which leads to a risk of corrosion by sulphuric acid attack. Corrosion by the effect of sulphuric acid begins when the temperature of the gas side of the economizer is equal to or less than the dew point of exhaust gases, which depends upon sulphur content in the fuel. To avoid this risk, the outlet temperature of the boiler was limited by 180°C, but after the energy crisis this limit is reduced to 140°C, or even lower.

The higher efficiency of turbochargers, the higher output of the engines, and the improvements of thermal efficiency lead to use the constant pressure turbocharging, which is more efficient than the pulse pressure turbocharging system.

B & W claimed that the saving in (SFOC) was about 5% due to changing from pulse-pressure system to constant pressure system.

Another result of improving the efficiency of turbocharger, and marine engine design is the introduction of turbo compounding system (TCS), where a power turbine is connected in parallel with the turbocharger turbine.

By using (TCS), the (SFOC) was reduced by 2-5 g/BHPH on MAN - B & W type MC engines.

4) Using shaft driven generators:

The electricity production on board a ship is the second largest energy, so it will be very economical to produce this energy from the main engine. This practice reduces the cost of maintenance of auxiliary engines.

The IHI of Japan developed the ED-Drive (electronic differential epicyclic drive), which keeps the shaft generator speed, and the frequency constant between 90% and 40% of main engine load (10).

5) Improvements of the fuel injection system:

The conventional fuel injection system is modified to respond for the developments of the other systems of the marine engine and to burning heavy fuel efficiently. One very important improvement was the introducing of the variable injection timing (VIT).

The (VIT) system controls the maximum combustion pressure according to the load, i.e. at high loads the injection timing is automatically advanced to raise the combustion pressure, and to compensate for the short time of combustion results from the higher speed of the engine.

In RTA-Sulzer engines, the (SFOC) was reduced by 2 g/bhph at 85% engine load when the (VIT) is used, where the (SFOC) for this large engine is reduced to limits between 116 and 118 g/bhph. At low loads the (SFOC) is reduced also by introducing the controllable opening pressure fuel valve, which raises the injection pressure at low loads, to improve the combustion, and consequently reduce the (SFOC) at low load.

The latest development in the fuel injection system is the electronic injection system, which is used on (MAN-KEZ) engines. The electronically controlled fuel injection system enable the engine to operate at the optimum injection pressure and timing at all times.

This system is introduced only to MAN - engines, and till now it is supposed to be under test.

REFERENCES:

1 - Marine Diesel Engines, C.T. Wilbar, D.A. Wright, Butterworths - 1986.

2 - 2-Stroke MC-engines (MAN - B & W) - 1987.

3 - Diesel Engine Design, T.D. Walshaw, London, 1953.

4 - HANSA - Number 18/19 - 1986.

5 - The Motor ship - May, 1982.

6 - HANSA - Number 8, 1986.

7 - HANSA - Number 14, 1986.

8 - Project Guide two stroke Engines, MC Programme, Vol. 1, Ed. 2, 1986.

9 - Motor ship, March, 1985

10 - Marine Engineering/Log, March, 1984.

11 - Lloyd's Ship Manager, March, 1988.

SLOW AND MEDIUM SPEED MARINE DIESELS

Hamid Shahad Al-Hamza & Joma Al-Fallah

University of Al-Fateh

Marine Engineering Department

Tripoli, Libya

ABSTRACT

In this paper, the subject of using the marine diesel engines, as main engines in the merchant ships is to be discussed. The modern modifications in the marine practice of propulsion will be focused on.

There are no clear limits to identify the marine diesel engines according to their speed of rotation. Those engines may be classified in different ways, from one first to another. According to the classification of the Society of Naval Architects and Marine Engineers (SNAME) the marine diesel engines may be classified into three types:

1. Slow speed diesel engines,
2. Medium speed diesel engines,
3. High speed diesel engines.

The low speed diesel engines may be defined as those engines of rotating speed ranging between 100 rpm and 514 rpm, or, those engines where the main piston speed is ranging between 1000 fpm and 1500 fpm.

The slow speed diesel is a direct-drive engine, since the speed of the engine is slow enough to give the highest efficiency of the propeller. As the engine is a direct-drive, then it must be rotating in clockwise and counter clock-wise directions, to enable the reverse speed of the ship.

The medium speed diesel engines are those engines where the speed of rotation is ranging between 700 rpm and 1200 rpm, or the main piston speed is ranging between 1200 fpm and 1800 fpm. The medium speed engines are indirect-drive engines, since the engine is not suitable to give high efficiency of the propeller, so there must be a mean of mediation between the engine and the propeller, this mean may be mechanical as a reduction gear or electrical as a generator.

The reduction gear may expand 1.5% to 2% of the engine power, but it may improve the propulsive efficiency of the ship, by giving a wide range of propeller designed speed control. In this paper, only slow speed and medium speed diesels are to be dealt with, since the high speed diesels are rarely used as main engines in the merchant ship. The main features of both engine types will be clarified, stressing on the advantages of both engine types in the marine practice. Although, the slow speed diesel engines have been given more attention since the energy crisis of 1973 due to its low specific fuel consumption a recent development in the area of improving the thermal efficiency of both types is focused on.

***

First of all I have to answer this question: When the diesel engine is considered as a slow speed engine? and when it is considered as medium speed one?

There are no clear limits to define whether the engine is slow speed, or medium speed. Some authorities classify the marine diesel engines to three classifications:

1. Slow-speed marine diesel engines
2. Medium speed marine diesel engines
3. High-speed marine diesel engines.

According to this classification the engine is categorized as slow, medium or high speed engine according to the following table (1).

	Piston speed, fpm (m/s)	Shaft speed, rpm
Slow speed	1000-1500 (5-7.6)	100-514
Medium speed	1200-1800 (6.9.14)	700-1200
High speed	1800-3000(9.14-15.24)	1800-4000

In the present day of marine practice the slow-speed engine is that of cross-head type, two stroke direct-drive engine, where the turning speed is ranging between 180 rpm and 65 rpm. To improve the propulsive efficiency the lower limit of the engine speed may be 60 rpm or even less.

The medium-speed engine is, indirect drive, trunk-piston type, four-stroke, operates at 400-600 rpm, in the larger sizes (2).

In some particular cases the turning speed of the medium-speed engines may approach 1000 rpm. The propulsive efficiency of the propulsion power plant, is highly affected by the propeller diameter and its turning speed. In the past the diameter of the propeller is limited by 22 ft, as maximum because of manufacturing and transport considerations. Now-a-days the maximum diameter of the propeller may exceed 11 m (36 ft),which means that there is a large field of freedom to match the suitable propeller with the suitable turning speed.

Another variant comes to serious consideration, which is the price of the fuel, where the improvement of the propulsive

efficiency is of great role to reduce the fuel cost. The speed of the slow-speed engine was seldom lower than 100 rpm, because lower speed leads to higher weight of the engine, as is shown in Fig. (1).

At the same time a slight sacrifice of thermal efficiency was accepted, as the price of fuel was low.

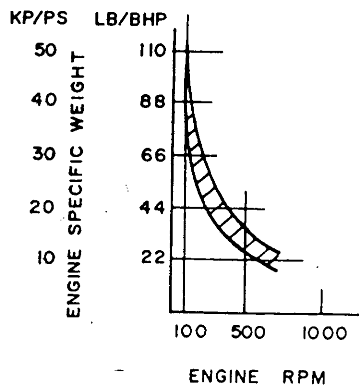


Fig. 1 Weights of low-speed engines

Fig. (1) From Ref. 1.

The latest generation of slow-speed engines are not so massive, compared to those of the preceeding generation, thanks to the reduced bore, super long stroke design feature, which was behind this result.

The propulsive market for ocean-going ships today is dominated by two-stroke low-speed diesel engines, which account for about 75% of installations in the recent years (3).

The main reasons behind this domination are:

1. Low specific fuel consumption (SFC):

The slow-speed diesel engine is the most suitable engine to burn heavy fuel, with the least (SFC) among all other marine diesel engines. Heavy fuel is used now even in high-speed engines, but the slow-speed is the most efficient engine in this respect where the (SFC) is reduced to about 114 g/bhp.h corresponding to thermal efficiency of 53 - 54% (3).

Not only (SFC) is reduced but also the specific lubricating oil consumption is reduced to about 0.5 g/bhp.h where it is about 1.2 g/bhp.h in the medium speed diesel engine (4).

2. The high output of the cylinder in the slow-speed diesel reduces the number of cylinders required for a given power, and consequently the number of moving parts is reduced, which leads to lower maintenance work and cost.

The length of the slow speed engine, which is one of the important objections against it, it also reduced in some design by integrating the thrust block into the bedplate, a practice

followed by Sulzer in the (RL-type) engines.

This reduction in length of the engine is of high importance, since the length of the ship is the most expensive parameter in the design of the ship, while the height of the ship is the only free dimension, which facilitates the use of superlong stroke engines.

3. Low engine speed:

The long stroke diesels improve the propulsive efficiency by reducing the propeller speed, without need to mediator, such as the reduction gear, which cause a loss of power in the range of 1-2% of the total transmitted power.

To know the effect of slow-speed of the propeller, it is suitable to say that:

(It is a generally accepted standard value that the power required decreases by 3% for each 10 rev./min. reduction in propeller speed). (5).

Moreover the slow speed of the engine improves its ability to burn heavy fuel, as there is more time available to compensate for the ignition delay of the heavy fuel.

Low-speed reduces the inertia forces acting upon the engine components, since: inertia force V^2. That means that the service life of the engine components is increased compared with medium-speed engine.

The cost of repairs of the slow-speed engine is supposed to be more than that of the medium-speed engine, but "MAK claim that the cost of repairing a cross head engine is 20% less than that of a medium-speed diesel of the trunk type"(6).

This claim may due to establishing special service centers at all principal ports, supplied with efficient logistic facilitations.

On the other hand the slow-speed diesels are not free from some drawbacks as:

- When operating at part load (below 45-50% MCR) the slow speed engine requires axiliary blower, which may expend 0.8% of the main engine output (6).

- To drive a generator from the propeller shaft it is necessary to have a step up gearing which costs about ten times the cost of a shaft driven generator by medium-speed engine (5).

- The cross-head engine is not suitable to be installed in continuous deck ships, such as car ferries, as the height of the engine disturbes the design of the ramp.

The medium-speed diesel are used as main engine with reduction gears, where the loss of power transmission through reduc-

tion gear approaches 2%, or as diesel electric drives, where the loss is more.

The main advantages of the medium speed engines compared with slow-speed engines are:

1 - There is a large space of freedom to choose the suitable turning speed of the propeller, to compensate for the loss of the reduction gear.

2 - Low capital investment, as the cost of a four-stroke medium speed of the trunk type is ranging from 60 to 70% of that of a two-stroke cross-head diesel of the same power (6).

3 - Low weight of engine and reduced space requirement, where saving in space is about 30% and saving in weight approaches 300%. For cross-head engine the weight to power ratio may be about 35 Kg/hp, while for a medium-speed geared engine the ratio is 12 Kg/hp.

4 - The maintenance work required for a medium-speed diesel is lower than that required for a slow-speed diesel, which is an advantage for ships, and multi-purpose ships. So a twin medium speed engines is more suitable, for the sake of less maintenance work time, where this time is available from three sources:

   a) From the waiting time outside the port, where one engine is in operation while the other is underm maintenance.

   b) From the stopover time in the port,

   c) From the slow-steaming time with one engine.

5 - Medium-speed diesel may be used as multi-engine plant, where there are many possibilities of enhancing the reliability and safety factor. They may be used as in-line or vee shape engine.

6 - The medium-speed engine may be located as far aft as possible, an advantage of giving more space to cargo.

REFERENCES:

1 Marine Engineering, SNAME, 1980.

2 Marine Diesel Engines, C.T. Wilbar, D.A. Wight, Butterworths, 1986.

3 HANSA 14 - 1986

4 Marine Diesel Engine (Principle & Practice) by D.K. Sanyal, Bhandarker Publications, Bombay 400016, June - 1981.

5 The Motor ship, November, 1980.

6 Marine Internal Combustion Engines, by A.B. Kane, Published by MIR Publishers, Moscow.

Alcohols as an Alternative Fuels
for Internal Combustion Engines

Dr : Gamaleldin A. Khalifa
Faculty of Science and Technology
University of Gezira P.O. Box 20
Wad medani , Sudan.

ABSTRACT :-

Untill recently , petroleum derived fuels; primarily gasoline and diesel, have been preferred because they are available and less expensive than any other forms of fuels. Several factors will force consideration of other types of non-petroleum alternative fuels. Those factors are briefly out lined and the requirements that must be met by such an alternative fuel are stated. Comparison of properties between alcohol fuels and petroleum fuels is made. Also some possible potential problems with alcohols are discussed with some methods for producing such fuels. Methods for utilizing alcohols fuels in internal combustion engines is detailed with a brief discussion on fumigation as a vaiable method in compression ignition (CI) engines. Performance characteristics, emission and fuel consumptions results of some tests are outlined.

INTRODUCTION :-

Indicators point to the fact that there will be a short fall of approximately 25% in crude oil supplies relative to demand by the end of this century. Dwindling fuel reserves and increasing fuel consumption are the main factors. Politics as well as economics in both importing and exporting countries plays a major role as to the use of alternative fuels in internal combustion engines.

The useof alcohol fuels as a supplement to, or replacement for, liquid fossil fuels in the transportation and agricultural sectors has received significant attention. Special attention is given to ethanol and methanol as fuel contenders in both spark ignition and compression ignition engines. Extensive research has been carried out on a variety of engines. Tests show that, in general, spark ignition engines are capable of performing satisfactorily on mixtures of alcohol and gasoline or entirely on alcohol. In the diesel engine area, engine configuration as well as the method of utilizing the alcohol fuel, complicates the picture.

Several factors will force consideration of other types of non-petroleum alternative fuels, some of these factors are :

1. Oil reserves are declining world wide.

2. Demand for oil is increasing.
3. Politcal consideration may disrupt the availability of pertoleum fuels for some importing countries.
4. Economical considerations.

The use of any other form of fuel in the automotive and transportation sectors is governed by certain criterias and must meet the following requirements.

1. Availability and abundancy of the source.
2. Technically known methods of production.
3. Economically feasible cost of utilization of production methods.
4. Possible adaptability to existing types of engines with or without minor modifications.

The most promising alernatives to gasoline and diesel fuels are : Liquid hydrocarbons from tar and oil shale; synthetic fuels from natural gas and coal; alcohols; particularly ethanol and methanol.

Alcohols may not necessarily represent the most resource efficient or cost-effective use of available fuel feed stock; however it is generally recognized that these are among only a very few alternative energy sources which resemble current used petroleum fuels and permits usage with minimal modifications. In this paper only Ethanol and methanol are considered. Higher Alcohols are not considered here because of their limited supply from other than petroleum sources and at the same time, they are valuable for other specific uses and are generally more expensive.

Ethanol is produced by one of two processes :

1. fermention of grains and other sugar or starch feed stocks.
2. synthesis from ethylene.

The first method could be utilized by farmers and produce self sufficient fuel. The second method is from a petroleum distillate and is not considered here as a viable alternative.

Methanol can be produced from coal, natural gas and waste wood. Its production involves a catalytic reaction of carbon monoxide and hydrogen.

To better understand the differences between ethanol, methanol, gasoline and diesel fuel, a table was constructed.

It can be seen from the table that ethanol and methanol, unlike gasoline or diesel fuels, are single chemical compounds with sharply defined boiling points. Their molecular structure includes an (OH) or hydroxy radical which gives them certain characteristics. Some of the effects of alcohol fuels properties can be summarized as follows :

A. The high octane number of alcohols makes them inherently adaptable as fuels for conventional spark-ignition engines.

B. The low cetane number makes them less adaptable to compression-ignition engines. This seemingly formidable problem can be solved by the method of partial substitution of the fuel, by fuel additives or by some engine modification

such as start assisted diesel.

C. The high latent heat of vaporization of alcohol normally has a cooling effect which reduces the charge temperature and thus usually improves engine volumetric efficiency. But on the other hand it will not evaporate as readily without the increased addition of heat, especially at low ambient temperatures.

D. Difference in vapor pressure, volatility and boiling point range will have a general effect on startability, warm-up and acceleration, as well as the occurrence of vapor lock.

E. Alcohol fuels have far less heating values compared to petroleum fuels. Tank capacity should be increased to attain the same distance travelled. The air-fuel ratio will generally have an effect on engine power output.

F. Safety problems must be addressed. Ethanol is not as dangerous as methanol, which is a cumulative toxin.

G. Table showing possible potential problems with alcohol fuels was constructed. These are divided into six major parts : distribution and handling, compatability with materials, vehicle performance, environmental effects, toxicity and economic factors. It could be seen that many of the problems could be solved by engine or fuel modifications.

It could be generally stated that the technical problems with ethanol are similar to that of methanol. Most of the properties of ethanol are intermediate between petroleum fuels and methanol. Those differences as well as experience indicate that potential problems with the use of ethanol would be less severe than those encountered with methanol.

ALCOHOLS IN S.I. ENGINES :-

The use of ethanol and methanol either blended with gasoline or by themselves in automotive engines for transportation purposes attractive for the following reasons:

1. Feasibility of operating current automotive engines with a minimum of design modifications.
2. Possibility of attaining modest improvements in engine performance and exhaust emission.
3. Capability of alcohol manufacture from renewable resources.

Due to the high octane number of ethanol and methanol, they are best suited for S.I. engines. For these fuels to be used in current S.I. engines, they should provide:

- Acceptable performance, regarding cold starting, warming up, hot driving and general acceptable acceleration.
- Acceptable fuel consumption and power output, with the least emission possible.
- Stable fuel composition under all climatic conditios.
- Compatability with normal production vehicles, concerning materials used and engine lubricating oil.

Acceptable availability of the fuel as well as an economical production method.

To use alcohol fuels in S.I. engine different methods have been suggested and used :-

1. Blending with gasoline.
2. Emulsion with gasoline.
3. Dual fueling.
4. Using straight alcohols.

All of these methods use the carburetor of the engine for introducing the fuel.

1.<u>Blending with Gasoline</u> :-

Ethanol and gasoline are miscible in all proportions. Blends are normally sensitive to water and have very low tolerance, although the water tolerance increases with higher percent of ethanol concentration. At best anhydrous ethanol-gasoline blends should be used. This restriction prevents the use of low proof alcohols without the addition of stabilizing additives.

The best known blend is gasohol (10% anhydrous ethanol + 90% gasoline).

- Blends show increase in octane number.
- Positive volume change was encountered.
- Better miles/Btu and higher efficiency.
- No unusual wear or deterioration of the engine as a result of using gasohol.
- Less Co emission and about equal NOX and unburned hydrocarbons.

2.<u>Emulsion with Gasoline</u> :-

The Ontario Research Foundation (ORF) has developed a mechanical emulsification device using the vortex principle or the hydro shear concept compatible with installation in the fuel line of both diesel and spark-ignition engines. The main objective is to solve problems with cold weather operation and avoid phase separation in winter time as is the case with unemulsified blends.

3.<u>Dual Fuel Operation</u> :-

Starke investigated the addition of a second fuel container, a second fuel pump as well as metering instruments on a V.W. Scirocco equipped with a two step register carburetor. Since this carburetor consists of two separate floats; gasoline could be charged through one while methanol/water mixture could be charged through the other.

4.<u>Using Straight Alcohols</u> :-

S.I. engines can burn straight alcohol if properly designed and calibrated for the fuel. Anhydrous or water/alcohol mixture can be used and as low as 160 proof has been attempted. The metering system for S.I. engines can only be calibrated for one specific mixture. Changes in water/alcohol concentrations can not be tolerated.

Modifications required to utilize alcohol fuels in S.I. engines with best fuel economy are :

1. Carburetor recalibration to produce and maintain the required air-fuel ratio.

2. Ignition advance needs to be modified.
3. Some materials in the fuel system may need to be changed due to the possible reaction between these materials and the alcohol fuel.
4. Intake manifold needs to be heated to retain good cylinder to cylinder distribution and better evaporation of the alcohol fuel.
5. Starting aid devices may be needed, especially at low ambient temperatures.
6. Advantage of high octane number can be utilized by increasing the compression ration (C.R.) for better fuel economy.
7. Larger fuel tanks may be needed due to the low heating values of alcohol fuels.

Staright low-proof ethanol was used in our S.I. engine tests. Caburetor calibration was the only engine modification for that particular test.

ALCOHOLS IN C.I. ENGINES :-

Alcohols, whether being anhydrous or wet, are poor diesel fuel. This is mainly due to the low cetane number of the fuel which indicates a poor autoignition quality and long ignition delay. Normally a minimum cetane number of 40 is required by the ASTM test, while methanol and ethanol have a cetane number of less than 15.

The main difficulty with alcohol fuels is the intiation of the flame. Other alcohol fuel problems in C.I. engines is their poor lubricating ability in contrast to diesel fuels. This is important when alcohol fuels are injected through injectors in the combustion chamber as this may normally cause injector tip wear. Due to the high enthalpy of vaporization of alcohol fuels; a significant cooling effect of the intake charge occurs. This normally causes excessive ignition delay, quench or cold starting problems.

An important factor is the possible phase separation if mixtures of ethanol and diesel fuel are used, particularly if a small amount of water is present. The wider flammibility range of alcohol fuels make them more hazardous than normal diesel fuels.

To overcome some of these problems, different approaches of utilizing alcohol fuels in diesel engines have been used. These methods can be divided into five classifications.

1. Fuel modifications.
2. Solutions.
3. Emulsions.
4. Engine modifications.
   a. spark-assisted diesel.
   b. surface ignition.
   c. twin injectors.
5. Fumigation.

The percent of diesel fuel substitution when using alcohol fuels as well as the power output, efficency, exhaust emission, phase separation, engine wear and lubricants degradation were the focus of many investigators. The effect of many parameters such as ignition delay, compression ratio, injection timing and rate have also been reported. Previous puplications when using alcohol fuels in diesel

engines are listed below, according to the method of utilizing the alcohol fuel.

1. <u>Fuel modifications</u> :-

The only possible way to use alcohol fuels in C.I. engines as a total replacement to diesel fuel without engine modification is by using fuel additives. These fuel additives should fulfill two objectives :

A. Improve the cetane quality of the fuel.
B. Enhance the lubricating ability of the fuel.

2. <u>Solutions</u> :-

In S.I. engines gasohol, which is a solution of unleaded gasoline and ethanol, is used. Similar mixtures of diesel fuel and alcohol are not a viable alternative. Methanol is completely insoluble in diesel fuels. Anhydrous ethanol is soluble in diesel fuels, but it's water tolerance is extremely low and the mixture is generally very unstable. Small amounts of water in the ethanol or diesel fuel, or entering the tank through normal breathing could cause phase separation.

3. <u>Emulsions</u> :-

Emulsion as regarded here is the dispersion of small droplets of alcohols into the diesel fuel. This emulsification can be achieved either chemically by adding chemical stabilizers known as surfactants or mechanically by using an emulsifier. Chemical stabilizers are expensive and about 10% or more by volume is needed in the fuel.

4. <u>Engine modifications</u> :-

Since alcohol burns readily when an ignition source is supplied, several diesel engine concepts have been reported.

<u>A. Spark-Assisted</u> :- Foster and Adelman reported the work of several authors. Investigators generally showed this method to be a technically feasible method.

<u>B. Surface Ignition</u> :- The main idea behind using the surface ignition method is to initiate the flame by injecting alcohol so that it impinges on a hot surface which would result in ignition. This method is still experimental and is done on a single cylinder engine. The hot surface has to be heated externally to a temperature of 1000°C.

<u>C. Twin Injectors</u> :- This is the idea for pilot injection. The pilot, which is the diesel fuel, is injected through one of the injectors while the alcohol fuel is injected through the other injector. An engine with a special head with two injectors is required.

5. <u>Fumigation</u> :-

This is a process where part of the fuel is supplied by alcohol through the engine air intake. The remaining diesel fuel is delivered normally by a high pressure injection system into the engine cylinder.

The alcohol injected in the intake air passage vaporizes and forms a combustible alcohol/air mixture.

The idea is to provide a lean alcohol fuel mixture which would be ignited by the flame from the diesel fuel. In essence this method of operating the engine is a combination of premixed alcohol charge burning and diesel diffusive combustion.

Normally a separate alcohol fuel system, including fuel tank and delivery components, is required. Performance of the alcohol injection system is very important. Variables such as alcohol atomization, droplet size variation, fuel vaporization, intake manifold temperature depression, alcohol-air mixture uniformity, engine volumetric efficiency and cylinder to cylinder uniform distribution is very important.

Due to the vaporization of the alcohol fuel and the consequent temperature drop, a generally excessive ignition delay and rapid rate of pressure rise were noted at high alcohol fuel flow rates.

Many systems for alcohol fumigation have been investigated. The two most commonly used are :

A. Alcohol carburetion.
B. Air-assisted nozzles fumigation.

CONCLUSTION :-

It could finally be noted that the use of alcohol as a motor fuel is expected to be a two - fold benefit.

1. Could save a considerable percentage of petroleum-derived fuel, and hence will reduce dependency on foreign oil inports.
2. Better combustion quality with better environmental consequences. Lower emission of certain gases into the atmosphere is expected - NOX to mention one.

In the under-developed world, hard currency would be saved, unemployment would be reduced due to the installation of new factories that manufacture the fuel and the general situation for these countries would improve.

▼

Properties of Ethanol, Methanol,
Gasoline and #2 Diesel Fuels

Property	Ethanol	Methanol	Gasoline	#2 Diesel
Formula	C_2H_5OH	CH_3OH	Mixtures of Hydrocarbon	
Molecular weight	46.07	32.04	--	--
Composition weight Carbon	52.20	37.50	85.88	87
Hydrogen	13.10	12.60	12-15	12.6
Oxygen	34.70	49.90	0	0
Specific gravity 60°F/60°F	.794	.796	.72-.78	.86
Density lb/gallon	6.61	6.63	5.8-6.5	6.7-7.0
Boiling point °F	172	149	80-437	363-652
Flash point °F	55	52	-45	118-220
Autoignition temp °F	793	867	495	--
Flammability Limits				
Vol. % Lower	4.3	6.7	1.4	.6
Higher	19	36	7.6	6.5
HHV Btu/lbm	12,800	9,750	20,260	19,550
LHV Btu/lbm	11,600	8,600	18,900	18,500
LHV Btu/gallon	76,700	57,000	130,000	128,000
% of Gasoline LHV	61	46	100	98
Latent heat of vaporization Btu/lbm	362	474	170	250
A/F Ratio Stochiometric	9.01	6.45	14.6	14.6
Octane No. Research	111	112	91-100	--
Motor	92	91	82-92	--
Cetan No.	<15	<15	<15	40-60
Vapor press (psi) at 100°F	2.25	4.6	9-13	.04
Energy Btu/ft (Standard Stochio)	94.7	94.5	95.4	--
Solubility in water	infinite	infinite	insoluble	insoluble
Toxicity	irritant, toxic only in large doses	irritant, cumulative toxicant	moderate irritant	moderate irritant

Possible Potential Problems with Alcohols (ethanol and methanol)

Problems	Probable Occurrence
1. Distribution and Handling	
A. Phase separation	Definite
B. Incompatability with fuel	Possible
C. Hygroscopicity	Definite
D. Volume change in blending	Probable
E. Storage stability	Possible
2. Compatibility with Materials	
A. Metal corrosion	Definite
B. Non-metal compatability	Definite
C. Lubricant compatability	Possible
D. Internal engine wear and rust	Possible
E. Fuel pump wear	Possible
F. Dirt lossening and filter pluggings	Probable
3. Vehicle Performance	
A. Cold startability	Definite
B. Warm up derivability	Definite
C. Vapor lock	Probable
D. Preignition	Possible
E. Low cetane quality	Definite
4. Environmental Effects	
A. Vapor recovery in distribution system	Unlikely
B. Environmental effects on spills	Definite
C. Exhaust Emissions	
- unburned alcohol	Definite
- Aldehyde	Definite
- odor	Probable
5. Toxicity and Safety Precautions	
A. Toxicity	Definite
B. Vapor explosivity	Definite
C. Fire Problem	Possible
6. Economic Factors	
A. Economics relative to petroleum fuels	Definite

REFERENCES :

1. U.S. National Alcohol Fuels Commission; Fuel Alcohol: An Energy Alternative for the 1980s, Final Report.
2. Thring, R.H. ; "Alternative Fuels for Spark Ignition Engines," SAE 831685.
3. Bro, Klaus and Pedersen, P. S.; "Alternative Diesel Engine Fuels: An Experimental Investigation of Methanol, Ethanol, Methane and Ammonia in a D.I. Diesel Engine with Pilot Injection". SAE 770794.
4. Heisey, J. B. and Lestz, S. S. ; "Aqueous Alcohol Fumigation of a Single Cylinder D.I. Diesel Engine," SAE 811208.
5. Wagner, T. O.; Gray, D. S.; Zarah, B. V. and Kozinski, A. A. ; "Practicality of Alcohols as Motor Fuel," SAE 790429.
6. Alternative Fuels Committee of the Engine Manufacturers Association;" A Technical Assessment of Alcohol Fuels," SAE 820261.
7. Scheller, W. A.; "Test on Unleaded Gasoline Containing 10% Ethanol-Nebraska Gasohol," International Symposium on Alcohol Fuel Technology Methanol and Ethanol. Wolfsburg, Germany, Nov. 1977.
8. Lawrence, R. D. ; "Emission from Gasohol Fueled Vehicles," Third International Symposium Alcohol Fuels Technology. Asilomar, California, May 1979.
9. Slarke, K.; "Fueling the S.I. Engine with Gasoline/ Methanol Water Blends," International Symposium on Alcohol Fuel Technology Methanol and Ethanol. Wolfsburg, Germany, Nov. 1977.
10. Ecklund, E. E.; Bechtold, R. L.; Timbario, T. J. and McCallum, P.W.; "State of the Art Report on the Use of Alcohols in Diesel Engines,"SAE 840118.
11. Adelman, H.; "Alcohols in Diesel Engine - A Review," SAE 79095.
12. Pischinger, F. F.; "A New Way of Direct Injection of Methanol in a Diesel Engine," Third International Symposium Alcohol Fuels Technology. Asilomar, California, May 1979.
13. Holmer, E.; Berg, P. S. and Bertilsson, B. I.; "The Utilization of Alternative Fuels in a Diesel Engine Using Different Methods," SAE 800544.

MANPOWER REQUIREMENT PLANNING IN ENERGY ORGANISATION BY MODELLING

M.A. AL-FTISE
Atomic Energy Commission, Tripoli-Libya
FOUD MATUG
Department of Mechanical & Industrial Engineering
Al-Raya Al-Khadra University, Tripoli-Libya
C.K. SINGH
Department of Mechanical & Industrial Engineering
Roorkee University, Roorkee, India

INTRODUCTION

The instantaneous boom in the oil prices during the decade 1970 and a regular fall in the oil prices thereafter created not only an unprecedented perturbation in the world economic balance but also a serious reduction in the production of the oil. Both the factors have created a wider gap between the demand and production of the energy through out the world. Today everybody is energy conscious and every oil producing country is determined to conserve the oil reserves to last for a longer period. The developed countries are spending more to meet their ever rising demands whereas in the developing countries the cost of meeting the energy demand far exceeded their budgets. No doubt efforts are being made to exploit alternative resources of energy on viable level but the management can work out a solution to the problem by considering the available resources, magnitude of demand and the constraint. Amongst the resources, manpower is one of the prime constituent. The availability of a sufficient number of qualified manpower at the time when they are needed is one of the essential functions of the management. For the success of any program in the reliable production of energy and the development of national infrastructure an excellence in human performance is necessary to carry out such functions as R & D, planning, construction, operation, safety and reliability.

Manpower Requirements

The world is presently passing through a phase of energy crisis and therefore every nation has a primary responsibility for planning and development of manpower program to face the challenges due to every odd being created by the crisis. The first fundamental step is to list down the functions of any organisation for producing the energy. The tasks and activities for which manpower requirement is to be assessed, can be listed as shown in Table I.

Quantification of manpower requirements alone is insufficient. In the modern times of specialisation the requirement has to be based on two such factors as expertise (including qualifications) and excellence (including

experience). The over all manpower requirements are then compiled by the sum of all tasks and activities in each stage of every project or program vis-a-vis the consideration of expertise and excellence. The process of planning of the management of an organisation becomes simpler with the help of a model that has in it all the identified factors. For the purpose of the development of such a model, all tasks and classes of personnel both at professional and technicians levels have to be identified. Efforts must be made to include on-job experience in the model as skilled and proficient manpower makes the project go smoothly as scheduled.

Manpower Planning Factors

A power generation program consists of a series of power projects. Each project requires a series of activities to be performed by qualified staff according to a certain schedule for which there cannot be any set of firm rules in any country or organisation. However, a set of tasks as listed in the Table I may be found at every place for which highly trained manpower is necessary at different levels. As technology is advancing at a faster rate than any classification of tasks and activities, the R & D (Research and Development) takes the top place. Also, once a project is put into commission the tasks which follow thereafter are

- (i) operations and controls
- (ii) maintenance and services, and
- (iii) civil construction for any extension programs.

The manpower effort at each is expressed either as man-hours or man-years. Usually the persons required for operation and control of a plant is relatively large, some of them operating in the shifts. Qualification levels and experience have to be carefully established for each level (eg. senior operators, operators, assistant operators etc). The personnel may be required from such disciplines as Mechanical, Electrical, Instrumentation, Physics and Chemistry. Likewise, the requirements for other tasks can be spelled out.

Three factors are usually considered to define the technical qualifications: educational qualification, professional experience, and specialised training. The educational qualifications can be categorised into

- (a) Doctoral Degree
- (b) Master's Degree in Science/Engineering
- (c) Bachelor's Degree in Science/Engineering
- (d) Diploma in an Engineering discipline
- (e) Certificate in a technical trade.

Manpower Model

A set of informations are necessary for the development of any model. For a mathematical model, the informations are described in the form of variables which can be conveniently quantified. The following general criteria is applied to collect the informations from a source. Let this source be a power project comprising of a series of diesel engine-ac generating sets in the size range of 500 KW meant for an industrial unit.

1. Only those variables are included in the model which are required for determining the number and quality of personnels. These are:

(a) qualification and experience variable, τ
(b) tasks and activities variable, γ
(c) and available quantum of resources which is known a-priori, C.

2. Since there is no straight forward relationship among these variables, the relationship can therefore be expressed as follows in a most general form i.e.

$$\tau^{x} \cdot \gamma^{y} = C \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

where x and y are the exponents to be determined by the data available from the system under consideration.

3. The value of C (allocated funds or time) is known.

4. The variable for academic qualification and experience is quantified on the number of years spent in school and on professional job. For example a person spends 21 years of schooling to obtain a Ph.D degree and 8 years on professional work the value of τ is then 29 for this person.

5. The variable for tasks and activities is quantified. Lay out for quantification has been given in the Table II.

   The numerical values have been chosen arbitrarily on tasks and qualifications with the informations available in"a guide book for Manpower Development for nuclear power",Table III.

Algorithm:

The following steps describe the features of the algorithm for determining the values of the variables and the exponents:

1. Preliminary work be done for different values of x and y on the fixed values of C corresponding to which there is a small feasible value of γ in order to fix a value of x which will not make the system negative.

2. Obtain a value of y or a ratio of x/y $\lesssim$ 1.0

3. Slove for τ.

4. Plot a graph for x/y and τ to study the behaviour of x/y on τ for each feasible value γ.

ILLUSTRATIONS

The Equation 1 may also be written as follows to facilitate calculations

$$\ln \tau = \frac{\ln c}{x} - y\,\frac{\ln \gamma}{x}$$

$$= \frac{c}{x} - y\,\frac{\ln \gamma}{x} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

TABLE I

Task Layout for a Power Project Organisation

Sl.No.	Tasks
1	Pre-planning phase, involving the conceiving of energy project.
2	Planning phase, involving the detailing of energy project.
3	Selection and purchase of materials, equipment and components.
4	Construction phase
5	Commissioning phase
6	Operation and maintenance phase
7	Manpower development
8	Research and Development

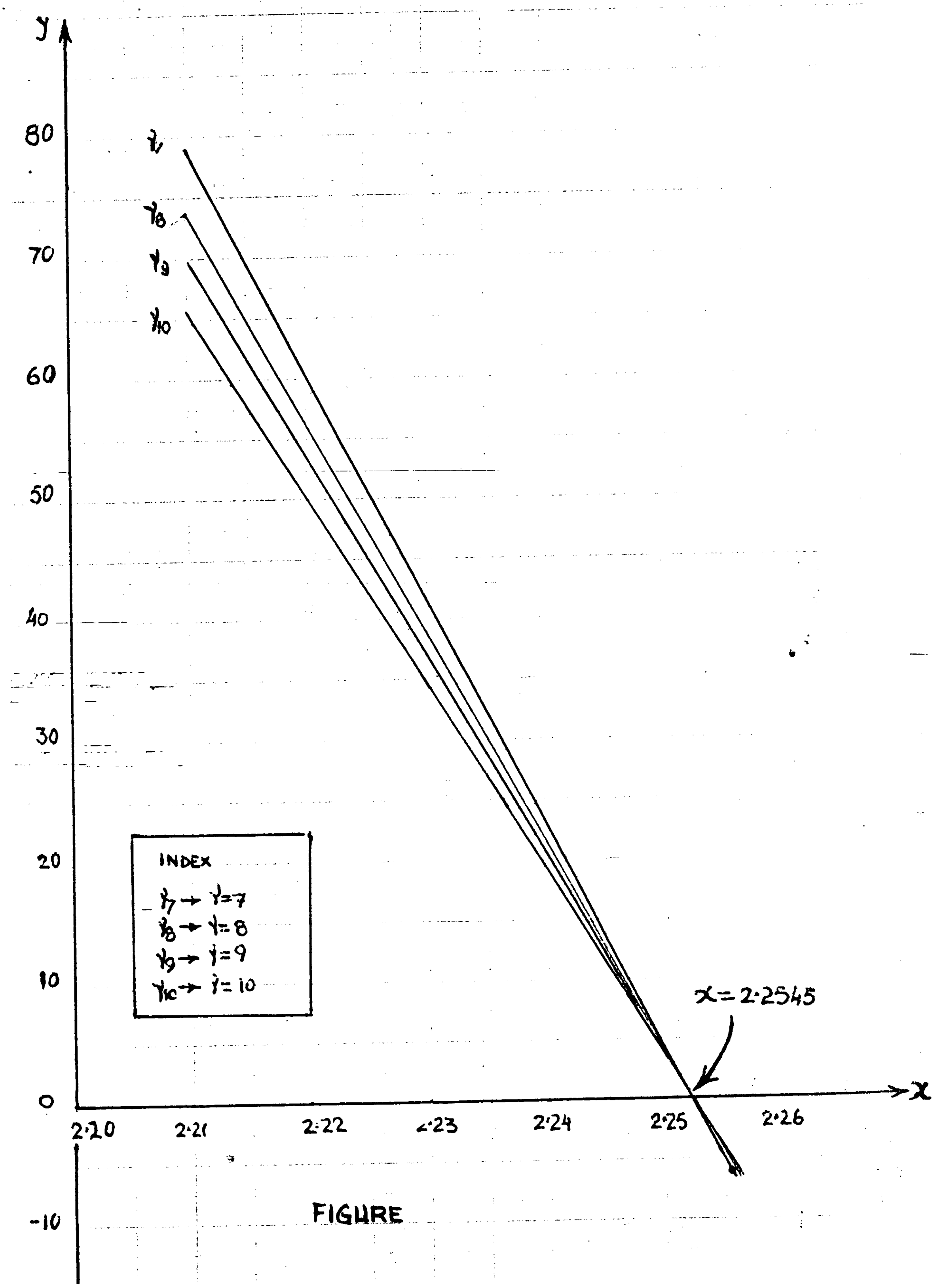
TABLE II

Quantification of Academic Qualification

Academic Qualification	Number of years	Tasks and Activities
Ph. D	21	R & D, Design, Training
M.S. / M. Sc.	18	Design, Training, Testing
B.S. / B. Sc.	16	Testing, Commissioning, Procurement
Diploma	12	Construction, Operation
Certificate	8	Construction, Operation, Services

TABLE III

Tasks/ Qualifications	R & D Design, Training	Testing Pilot Project	Commi-ssioning	Constru-ction	Opera-tion	Procurement	Services
Ph. D	5	5	4	-	-	-	-
M. S	4	4	5	1	1	5	-
B. S	1	3	3	5	3	4	1
Diploma	-	2	-	4	5	3	4
Certificate	-	1	-	3	4	1	5


y
80
70
60
50
40
30
20
10
0
-10
2·20
2·21
2·22
2·23
2·24
2·25
2·26
x
x = 2·2545
INDEX
$y_7 \to \gamma = 7$
$y_8 \to \gamma = 8$
$y_9 \to \gamma = 9$
$y_{10} \to \gamma = 10$

FIGURE

The values of C = 6930 man-hrs, τ= 29 and γ= 2 in one project.

The exponents x and y are determined with the consideration that and cannot take a value less than one due to their inherent nature. Thus there is a minimum value of x and y. To obtain these values consider the equation-3 derived from equation 2.

$$y = \frac{c}{\ln\gamma} - \frac{x}{\ln\gamma}\ln\tau \quad \ldots\ldots\ldots\ldots\ldots \quad (3)$$

$$= \frac{8.8436}{0.6931} - \frac{x}{0.6931} \times 3.3673$$

When a series of values of y are computed for several values of x the value of y takes a minimum positive value at x = 2.5. The variable x shall thus have a minimum value a given set of values of τ, γ and c. The figure shows the interrelationship between x and y for different γ at a set of known values for τ and c where it is advisable to adopt a value of 2.2545 for the exponent x. From the values of c = 1989 man-hours, x =2.2545, y = 0.0 γ = 10 choosen from a power generating unit, the computed value of τ is 29. Several combinations are possible for this value of τ = 29 and γ = 10.

(i) Ph.D with 8 years professional experience
(ii) M.S. with 11 years experience

The choice between the two alternatives is made on the economical analysis since the salary structure changes from place to place.

CONCLUSION

The paper treated a manpower modelling approach which until now has not been studied systematically. While presenting the fundamental functions of an energy producing organisation, it identifies and lists down the several tasks sequentially to facilitate the process of planning. The two basic parameters of man-power performance viz. expertise and excellence have been quantified for the purpose of the modelling. Besides the variables for expertise and excellence the model includes the parameter for the available resources. The interrelationship is described by a simple relation.

REFERENCE

[1] Technical Reports series No. 200
International Atomic Energy Agency, Vienna, 1980.

[2] Rivelt, Patrick - Principle of Model Building, New York: Wiley, 1972.

[3] de Neufville and Stafford: System Analysis for Engineers and Managers - McGraw Hill, New York, 1971.

SECTION III

EXPLORATION, DISTRIBUTION AND MANANGEMENT

AUTOMATION IN THE PETROLEUM INDUSTRY

A.B. Kieres
Intelligent Systems Laboratory
Department of Computer Engineering
Engineering Research Centre
Ar-Raya Al-Khadra University
Tripoli, G.S.P.L.A.J.

ABSTRACT

This study is aimed to project an overview of the deployed automation system in the petroleum industry. However emphasis is placed on computer application in the design, production and maintenance activities.

1. INTRODUCTION

1.1 Oil and Petrochemical Production

Prime objective of this paper, as outline above, precludes the parameters and details of oil, gas, water production and refining. Information on this subject readers attention is drawn to the reference [1] stated in the reference section.

1.2 Aim of Paper

This study aims to highlight the present computer applications for process control.

1.3 Reasons for Automation

The advent of petrochemical production and subsequent demand necessitate process optimization and cost effectiveness. This requirement deemed necessary to pursue automation of the production and reduce the reliance upon man-machine interface. Particularly when considering significant manpower cost.

To this end producers have endeavoured to effect the automation of the production ranging from simplistic indication instruments to the present prevailing state-of-the-art computer on-line control.

1.4 Automation

Process automation usually starts from the basic automation of instruments and distributed controllers then it progresses towards automation of process supervision, processing departments up to whole production.[2]
A discussion of automation is beyond the scope of this paper. However, in this respect the references [2-8] and [12] can be of interest to reader.

2. REVIEW AND ANALYSIS

2.1 The Design

Industrial process is firstly described and then all electronic parts to be used in production and measurements are presented. Physical simulation of the process is done. Also data acquisition and interfacing computer programs are prepared.[9]

Activities involved in process design include sketching the process flowsheet, control system design, hazard and reliability analysis, instrumentation, piping, utilities and cost design. The original design can be composed, totally new operations added, modified, stored, retrieved in interactive mood by the user on the graphical screens of a computer or on other graphical devices connected to a computer. [10], [8]
From plant layout information and production parameters an animated picture of plant can be obtained.[11]

2.1.1 Computer models

There are computer models for these activities. Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM) are defining a product and process to the actual designing and drafting. [12], [13] Computer Design (CD) and Computer Aided Engineering (CAE) prove to be useful in drafting architecture, parts of machines, production facilities [14], electronic systems[15], analysing costs [16], processing alternatives.[17]

2.1.2 Software programs

(i) CAD is of help in the designs in the pipeline[18], in the development of reliable multiphase pumps [10], in unit operations design[19], heat exchanger design[4], and underwater system design.[20] Programs for designing and analysing air pollution control equipment and estimation of capital and operating costs exist. [15]

A series of computer programs include designing of pressure vessel with vessel and accessory cost.[21] There is also a computer program for the mechanical design and analysis of tall vertical process towers.[4]

(ii) CD is used in switches and pump design, and in automated heat-tracing design for pipes and piping systems, and pumping unit design.[22]

(iii) The expert system for designing of conventional offshore oil and gas production facilities can perform all engineering decisions and calculations pertaining to design automatically. [14]

2.2 The Production

The electronic instruments and controls are used all along the oil industry production lines and automation is implemented. [1]

2.2.1 Enhanced Recovery

Computer simulation has improved oil recovery by making optimum use of the reservoir configuration and its properties. [23] It can also illustrate how polymetric diverting agents can be used by water control in waterflooding. [19] Analysis of Enhanced Oil Recovery Systems with the CO_2 injection is simulated too. [24] There is a control system capable of monitoring and controlling the operation of few injection wells. The electronic system controls injection pressure and rate of injection. [1]

2.2.2 The Pumps

Controls and supervision of beam pumps in onshore and submersible oil field are established around a microprocessor-based power-line carrier. The remote terminal unit (RTU) is connected to the electrical supply, the transducers on the pump, the motor starter. It receives and transmits signals on the network of substations. The pump is stopped automatically if anything out of the normal has occured or is about to occur. Its status and alarm signals are transmitted to a control centre. The control computer overviews and controls all the oil field. With its help the operator can see at once which pumps are running and which are not. Also remote control for obtaining required information about each pump is possible. [25]

Compact automated supervisory system for all kinds of rotary-type machines using pumps in petroleum industry is available. [4]

2.2.3 The Pipes

(i) Welding of pipes can be automatic, by the use of an electric unit which rides on the outside boundary of the line pipe being welded. [26], [27] Computerized control unit continually monitors the fusion cycle. [26]

(ii) Compact flow sensors are used to measure viscosity of crude and heavy oils. [28] Between other electronic devices, viscosity detectors are employed. They are installed directly into the pipelines or outside. [29]

Automation of an entire pipelines through a host computer engages a complete line of compatible and networkable controllers. [4] For example a pipe inspection camera is a portable system for finding out problems.

It points out the distance to problem areas and it is completely operational by remote control.[4] Corrosion, leaking and other internal and external influences over a pipeline can be reported accoustically and optically by the sensor line laid along it. [30] , [3], [4], [27]

(iii) A self-propelled robot goes into pipes and transmits back a video picture of the pipe's interior.[4]The teleoperated robot craws along the blowdown pipe inside a steam generator, a washes away harmful sludge. [31]

(iv) With the assistance of the PC, on an aircraft, which points out their optimal location[32] , very small aperture (satellite) terminals (VSATs) are installed as part of Supervision Control and Data Acquisition (SCADA) system. VSATs report automatically through the satellite to the control centers and host computer. [4] ,[8] The satellite network control centre can re-route the data to any site in the network. It also helps the software based commands from the master station to pass through. [33] ,[34]

2.2.4 The Pump station

Mainframe computers and other microprocessor based systems are designed for pump station terminal control. [33] In pump controls, automatic control valves for liquids including pressure reducing, pressure relief, flow control and so forth can be engaged. [4]

2.2.5 The Plant

(i) In process control, some of the self-testing sensors are automatic and based on electronics. They include compact flow sensors, ultrasonic direct mass flowmeters with an electronic control unit, viscometer and so on. They can automatically start up, take various measurements, record them and shut off. [3], [4], [10] ,[20] For instance remote intelligent sensors measure density, level, moisure, mass flow, volume in tanks and other vessels.[4] Conditions are controlled and automatically reported from the micro-processor based intelligent transmitter to PC for evaluation, analysis and print out.

In boiler-furnace control on-line measurements (oxygen, CO, hydrecarbon, capacity and temperature) may be transmitted to a computer-controller which offers several strategies to be taken in a given situation. [4]

Microprocessors based underwater system controls are ground fault indicators. [34]

(ii) Distributed control systems such as process measurements, laboratory analyses, inventory levels are transfered to a plant main-frame or mincomputer to be collected and verified and stored overthere in order to be available for access and applications. [4] ,[35]

(iii) The advanced control in process is performed by process control computers. The computer is employed in calculation of the physical properties of basic pure components and mixtures to be treated in a plant.

In the benzene unit, the computer control functions include controlling firing rate in the heater, and other controls.

Support to CAM and Computer Integrated Manufacturing (CIM) is given by control software packages. They cover many processes such as blending, dewaxing, lube oil extraction, plant information and so on. [4]

2.2.6 Off-shore automation

Automatic control systems are available for transportation vessels. [5] Software solves the floating equilibrium position of the vessel frm hydrostatic parameters while at the same time calculating flow conditions in pipe networks within the vessel and redistributing tank contents around vessel. [36]

The distributed digital control with supervisory computer exists for floating production vessels. It interfaces to other vessel systems, vessel stability, logging of alarms, events and operator actions. It reports on: well test and production, stability, ballast, mooring, performed operations, alarms, energy. [37], [38], [10]

There is also automation of monitoring and control of off-shore unmanned platforms which relate to the on-shore treating plant. The network of production and terminal platform, and terminal platform and gathering and treating plant are all equipped with electronic equipment and are connected to main operating centre. [35]

Electronics are applied in subsea well control system. [38] The work is in progress over the semi-submersible inspection vehicle-robot manoeuvred from the station. [39]

2.2.7 Expert systems for controls

Expert systems for the different controls are used in a production operation. [40] Expert system for example is engaged in real-time monitoring and analyzing process with values such as temperature and pressure data during plant operation. It can be used as an optimising tool. When the system for optimising strategies identifies anything out of the norm, it finds out the place of trouble graphically and gives advice visually and vocally about preventing such trouble further. [4]

An expert system for analysis of tower overhead problems exists. [41]

Already an interactive operation expert system for diagnosis and support of operation is used at ethylene plant. It can provide cause detection and counter-measures of malfunctions, operational data for optimal operation. [42]

2.3 The Maintenance

There is computer maintenance support, maintenance planning and scheduling, and material control. The maintenance of the process control system usually goes together with its repairs, modifications, extensions and lasts for several years after its installation.

Software supports control of maintenance operation. It also provides all aspects of corrective and preventive maintenance. Within that it includes estimating and capacity planning, work order scheduling, performance control, maintenance labour records, budget control, equipment history and inventory control.[43],[44],[45],[14]

(i) The work measurement software exists. It records and analyses of operations with up to nine different men or machines.[45]

(ii) Graphically supported documentation of functions covered by the process control is constantly updated by the software.[43]

(iii) In the oil movement package, the control centre is informed by operation personnel through RTUs about the product blend, flowrate, scheduling, quality data for the loading, shipping facilities. The data together with availability of required process units, operational parameters, connected equipment and associated inventory constitutes the dynamic DB. Such DB is manipulated by expert system to give optimality of control and monitoring of tankage, scheduling, planning, blending, products production and loading operations for tank farm, blenders, marine terminals, pipelines, trucks and railroad loading. [4]

(iv) An maintenance expert system for diagnosis and support of operation is used at ethylene plant. It can cover predictive and preventive maintenance information through analyzed historical data.[42]

3. CONCLUSIONS AND FUTURE

3.1 Conclusions

Computer application in the mineral oil industry was looked upon in CAD, CD, process control, and maintenance. It is observed that there has been an extensive development of automated electronic equipment employed in inspection, pipes, pumps, tanks, plants, vessels. Such electronic facilities have promoted further automation in the petroleum industry.

On the lower level of automation, the microcomputers, programmable logic controllers enable the machinery to which the electronic instruments are attached to run on its own. These electronic instruments are connected directly with on site PC or linked with monitoring and operational facilities of a main computer.

Either a human operator is informed about a dangerous situation on the computer screen or the operator will not proceed any further due to independent action of the electronic instruments.

On the next level of automation (production monitoring and control) computers are being used more and more to collect data from distributed production systems and to supervise them. Such intelligent systems perform control functions on their own. In some petroleum opertions they monitor every function and constantly inform the human operator about the operation state. So the computer controls and supervises some cycles of production.

These developments in the automation of the petroleum industry have been due to the computer software packages, particularly simulation.

These levels of automation on a small scale are enlarged to complete automation step by step. Already there have been signs of the automated, integrated production . It includes planning with CAD, CD, DBs, and CAE and manufacturing with CAM and CIM.

3.2 Future

It can be forseen on the lower level of automation integration of all types of sensors, automatic processing of major errors on measurements, periodical edition of the instrumentation guide for instruments maintenance. Software will aid towards better unit performance, simplification of instruments, better distribution of sensors and therefore fully automatic operation of data reconciliation.

On the advanced automation level the main computer should permit flexibility in a variety of systems layouts. New machines should be included to the system by adding new parameters to DB of computer.

There are indications of the independency of the highest level of sophisticated instruments and controls as a result of applying in them expert systems. The connection between process control system and expert system may be the key for future success.

The area of planning, scheduling and final product in the petroleum industry can be defined in a number of steps, therefore, it is likely to be run independently by physical machinery with aid of expert systems.

Although at present expert systems are restricted to a few dedicated tasks, the detailed knowledge of the petroleum processes which with time can be supplied, and manufacturing requirements which can be less complex than in other industries, classified them to be applied widely in the petroleum industry. Then all distributed control systems will reach the stage when they will handle all the on-line requirements and the host computer will carry on with the production computing.

All data and all operations will be collected, recorded and processed automatically. There will be automatic function documentation in the future.

Humans perhaps would be concerned only with what data should be processed first and then stored or just stored. The remainder, that is to say data processing, analysis would be performed by a machine perhaps in unknown for outside way. This will lead to the gradual changes in staffing and organisation of the petroleum industry.

There is no doubt that firmware items must still exist during operations such as carrying fluid and chemical ones connected with manufacturing of oil products. However, more and more often there will be instead of the man-machine, machine-machine interfacing.

4. ACKNOWLEDGEMENT

This paper is based on the publications available in the libraries of National Oil Corporation, and Agip Company of Tripoli, G.S.P.L.A.J. The authoress would like to express her thanks to Management of these libraries for use of materials and photocopying services. Also thanks are due to Mr.Khalid of Automation Division of Waha Oil Company in Tripoli for consultation and to Mr.Haidar of the same Company for providing the historical background of control and remarks about formal presentation of paper.

5. REFERENCES

[1] - Skinner, D.R., Introduction to Petroleum Production, Gulf Publishing Company, Houston, 1982.

[2] - Gore, F.E., "Plantwide computerization. Where are we now?", Hydrocarbon Processing, October 1987.

[3] - Newsfront. Chemical Engineering, May 1988.

[4] - Hydrocarbon Processing, March 1986, March 1987, March 1988, October 1986, 106, December 1987, 85,69,67,72,81,94, September, 1986, 78, November 1986, 162, January 1987,62, February 1986, 69, November 1987, 37-38.

[5]- Rodsten, S., "Asea Master goes offshore", Asea Journal 5-87.

[6]- Process control: What users say." Hydrocarbon Processing, February 1986.

[7]- Horn, D., "PCs Gain a foothold in factories", Mechanical Engineering, July 1988.

[8]- Pauly, T., "New systems philosophy for industrial automation", Asea Journal 5-87.

[9]- Phelps, C.H., and et.al., "Water Control in Secondary Operations", Proceedings of the Seminar on New Techniques of Petroleum Production, Damascus, Syria, 6-10 October, 1985.

[10]- World Oil, January 1987, 62, November 1987, 37-38.

[11]- Industrial Engineering, March 1988, 22.

[12]- Rembold, V., and Levi, P., "The factory of the 90s", Computers in Mechanical Engineering (CIME), March-April, May-June 1988.

[13] - Rodriques-Miaja, F.E., and Leesley, M.E., "Computer-Aided Project Evaluation for Chemical Process Plants", in Leesley, M.E., ed., Computer - Aided Process Plant Design, Gulf Publishing Company, Houston, 1982.

[14] - Aghili, H., and et.al., "Expert system designs offshore process facilities", Ocean Industry, June 1988.

[15] - Worley, F.L., Jr., "CEDA:Control-Equipment Design and Analysis", in Leesley, M.E., ed., Computer-Aided Process Plant Design, Gulf Publishing Company, Houston, 1982.

[16] - Lyche, D.W., "Economic Evaluation", in Leesley, M.E.,ed., Computer-Aided Process Plant Design, Gulf Publishing Company, Houston, 1982.

[17] - Petroleum Times, April-May 1988, 14-15.

[18] - "Designs in the pipeline", The Oilman, May 1988.

[19] - Lerou, J.J., and Froment, G.F.,"Unit-Operation Design. Fixed-Bed Reactor Design and Simulation", in Leesley, M.E., ed., Computer-Aided Process Plant Design, Gulf Publishing Company, Houston, 1982.

[20] - Underwater System Design, May 1987, 34.

[21] - Kirkpatrick, H.L., "Program designs and prices vessels", Hydrocarbon Processing, March 1987.

[22] - Landry, W.E., "Calculator program speeds pumping unit design", World Oil, November 1987.

[23] - "Sharpening the technological edge in oil", Marathon World 1987.

[24] - "Enhanced Oil Recovery", Progress Review. United States Department of Energy, September 30, 1986.

[25] - Danielson, E., and Ahlin, S., "Supervisory control sytem for beam pumps in oil fields", Asea Journal, 5-86.

[26] - Pipeline, March 1987, 24, 26, 38-39, June 1987, 21-22.

[27] - Madden, J., "The Piping and Layout Office", in Leesley, M.E., ed., Computer-Aided Process Plant Design, Gulf Publishing Company, Houston, 1982.

[28] - Pipe Line Industry, May 1984, 10, 60, 62.

[29] - Bos, A., and du Chatinier, J.G., "Simulation of Gas, Liquid Flow in Slug Catchers", SPE Production Engineering, August 1987.

[30] - Orzechowski, J., "Automatic Ultrasonic Wall Thickness Measurement in Pipe Extrusion", PE International Industrial and Production Engineering, June 2, 88.

[31] - Trovato, S.A., "Robot hunts sludge and hoses it away", Mechanical Engineering, May 1988.

[32] - Cramer, R.J.,"Over The Andes With Microwave", Pipeline, March 1987.

[33] - Mesh, G., "VSATs Bypass Leased Lines For Pipeline SCADA", Pipeline, June 1987.

[34] - "Pacific Texas Pipeline", Pipeline, June 1987.

[35] - Mori, L., "Unattended Platform Operation", Proceedings of the Seminar on New Techniques of Petroleum Production Damascus, Syria, 6-10 October, 1985.

[36] - Stewart, B., "First jack-up simulator will train rig crews", Ocean Industry, May 1988.

[37] - Munro, P.A.D., and Daniel, C.J., "Control system for floating production vessels", Ocean Industry, May 1988.

[38] - Franceschini, G., Chimisso, C., Lago, D., "Acoustic control system operates subsea well", Ocean Industry, May 1988.

[39] - Offshore Engineer, March 1988, 48.
[40] - Horne, D., "Artificial Expertise for Process Control", Mechanical Engineering, March 1988.
[41] - Kerridge, A.E., "Operators can use expert systems", Hydrocarbon Processing, September 1987.
[42] - "Expert System for Operational Defect Diagnosis of Ethylene Plants", Toyo Engineering Corporation (TEC) Advanced Engineering Information, March 1988.
[43] - "Process control technology, demand for flexibility", Chemishe Industrie International, March 1987. 28 32.
[44] - Pierce, F.R., "Maintenance: Do more with less", Hydrocarbon Processing, June 1986.
[45] - Chartered Mechanical Engineer, February 1987, 50.

SOME ASPECTS OF COMPUTER APPLICATION OF OPTIMIZING DRILLING HYDRAULICS

by

BEDNARZ S., W. FIGIEL , A. KESSLER

Stanislaw BEDNARZ Ph.D., M.Sc., Eng.- Visiting Professor of BSUT, Drilling and Production Equipment Departament of The St. Staszic Technical University of Mining and Metallurgy in Krakow, POLAND
Wlodzimierz FIGIEL Ph.D.,M.Sc.,Eng. - Visiting Professor of BSUT, Application of Computer Science & Metrology Dep. of The St. Staszic Technical University of Mining and Metallurgy in Krakow,
Adam KESSLER M.Sc., Eng. - Visiting Professor of BSUT, Drilling and Production Equipment Departament of The St. Staszic Technical University of Mining and Metallurgy in Krakow, POLAND.

ABSTRACT

The effectiveness with which a drillimg rig performs affects on economical profitability of whole oil and gas production process. The nature of the bottom hole cleaning for rotary drilling is still not sufficiently elucidated. To achieve good hole cleaning it is required optimal drilling mud circulation program (hydraulics program). Discussion in the paper is focused on bit hydraulic horsepower and impact force criterions. It is presented the math model of drilling hydraulics and its computer application for use in field practice. Selected data are presented in table form and some hard copy protocols from computer are attached.

1. INTRODUCTION

Fluid circulation system for rotary drilling consists of main components, accessory and auxiliary equipment (fig.1). The use of jet bits belonged to fluid circulation system requires properly designed bottom hole cleaning. Otherwise, the poor bottom hole cleaning can restrict the sufficient rate of penetration.

The amount of bottom hole cleaning required may be determined directly in field operations. In certain series of tests it was proved that rate of penetration improves with simultaneous increase of bit hydraulic horsepower and hydraulic impact force. It occurs with bigger intensity at surface horsepower increase. That tests should be run to some moment when relationship between drilling rate and bit weight is a straight line.The relationship of rate of penetration (ROP) and product of weight on the bit and

rotationl speed (W*R) is depicted in fig.2. The rate of penetration is directly proportional to bit weight if bottom hole cleaning is adequate. In coastal operations using mill-tooth bits, 5.2 bit hydraulic horsepower (BHHP) per square inch of hole is recommended by rule-of-the-tumb. Less bottom -hole cleaning is required for hard formations than in the soft formations.
AMOCO recommends 2.5 to 5 BHHP/sq.in. as a guideline for adequate jet horsepower. For penetration rates less then 10 ft/hr, 2.5 to 3 BHHP/sq.in. is the maximum they recommend. In general, the BHHP requirements depend upon formation, mud weight, penetration rate and the pressure difference between hydraulic pressure and formation pressure.

The design of a hydraulic program i based on maximizing bottom -hole cleaning and efficient lifting formation cuttings to the surface. The drilling cuttings generally have a specific gravity of 2.3 to 3.0 and an average of 2.5 can be assumed.

2. BASE ASSUMPTION OF OPTIMIZING CRITERION RATIO FOR HYDRAULIC PROGRAM

Optimizing of drilling hydraulics is accomplished in this paper by maximizing of bit hydraulic horsepower or maximizing of hydraulic impact force.This form of optimization was assumed for this paper purpose bacause:

- the use of maximizing of mud nozzle velocity in drilling industry is rarely applied
- the use of maximizing of rate of penetration (ROP) is very prospective but still not certain.

Determination of diameter of nozzles for the first and sequent bits run below the surface or intermediete casing requires the develope of microcomputer program for a better comfort, high speed and good accuracy.
Design of this program is based on work out of Hughes Tool Co. "Simplified Hydraulics", and Scott's method which can be recommended for Sirte Basin.

The total pressure losses in the circulating system are defined by the formula

$$Ps = k\ Q^{n}\ ,psi \tag{1}$$

where:

Q - flow rate of mud, gpm
k - constant affected by geometry of circulating system and density of mud
n - hydraulic exponent, primarily a function of the mud properties. This exponent as a slope of straight line plot of Ps vs Q on log-log paper can be measured while preparing drilling of the interval.

3. OPTIMIZING DRILLING HYDRAULICS PROCEDURE

This procedure involves:

- selection of optimizing criterion
- calculation of system pressure losses
- determining of initial circulation rate
- determining of system circulation rate

- sizing of bit nozzles
- determining of pump circulation rate.

3.1 SELECTION OF OPTIMIZING CRITERION

Maximum hydraulic horsepower is described by term (2)

$$Pb = [n/n+1]\ Psp \tag{2}$$

but maximum impact force by (3).

$$Pb = [n/n+2]\ Psp \tag{3}$$

where:

- Pb - pressure drop across the bit , psi
- Psp - standpipe pressure or maximum allowable surface pressure
- n - hydraulic exponent primarily a function of the mud properties can vary from 1.0 to 2.0 . Imco Service assumed 1.78, Reed Tool Co. - 1.82, H.A.Kendal & W.C. Goins - 1.9 and Hughes Tool Co. uses 1.86 (rule used in this paper calculation).

3.2 SYSTEM PRESSURE LOSSES

They are determined by term (4). In the case of shortage of field data to estimate n exponent it is assumed value 1.86 and for this case the system pressure losses Ps are given by terms (5) for BHHP and (6) for IF.

$$Ps = Psp - Pb \tag{4}$$
$$Ps = 0.35\ Psp \tag{5}$$
$$Ps = 0.52\ Psp \tag{6}$$

3.3 INITIAL CIRCULATION RATE

This circulation rate is described by transforming formula (7) to (8).

$$Ps = k\ Q^{1.86} \quad ,psi \tag{7}$$

$$Q = (P/k)^{1/1.86} \quad ,gal/min \tag{8}$$

where:

k - constant affected by geometry of circulating system and density of mud

$$k = 10exp(-5)\{Ce + [C3 + C4]*Lc + [C5 + C6]*Lh + Lp/Cp\}*w \tag{9}$$

w - weight density of mud, lb/gal
Ce - surface equipment loss coefficient determined from table ´.
Drill collar bore loss coefficient is calculated from (10) and drill collar annular loss coefficient from (11).

$$C3 = 6.1/Dcb^{4.86} \tag{10}$$

$$C4 = 8.6\ B/[(Do - D1)(Do^2 - D1^2)^2] \tag{11}$$

TABLE 1

Case	Stand pipe L	Stand pipe ID	Hose L	Hose ID	Swivel L	Swivel ID	Kelly L	Kelly ID	Coefficient Ce
1	40	3	45	2	4	2	40	2.25	19
2	40	3.5	55	2.5	5	2.5	40	3.25	7
3	43	4	55	3	5	2.5	40	3.25	4
4	45	4	55	3	6	3	40	4	3

L - length in feet; ID - inside diameter in inches.

Hevi wate pipe bore loss coefficient is given by (12) and hevi wate pipe annular loss coefficient by (13).

$$C5 = 6.1/Dhb^{4.86} \qquad (12)$$

$$C6 = 8.6\ B/[(Do - Dhw)(Do^2 - Dhw^2)^2] \qquad (13)$$

Drill pipe loss coefficient is reckon from (14).

$$Cp = 1/\{ 5.68/Dpb^{4.84} + 8.17\ B/X1 + 0.41/Djb^{4.85} + 0.43\ B/X2\} \qquad (14)$$

where: $X1 = (Do - Dp)(Do^2 - Dp^2)^2$

$X2 = (Do - Dj)(Do^2 - Dj^2)^2$

Value of B parameter is taken from table 2.

TABLE 2

Hole diameter	Parameter B
4 3/4"	2.0
5 5/8" - 6 3/4"	2.2
7 3/8" - 7 3/4"	2.3
7 7/8" - 11"	2.4
12" - 18 1/2"	2.5

Inside diameter of casing is put in place of diameter of hole, if the considered section of drill string is inside casing.
Pressure losses through and around the drill string and through the surface equipment are given by (15).

$$Ps = 10exp(-5)[Ce + (C3 + C4)*Lc + (C5 + C6)*Lh + Lp/Cp]wQ^{1.86} \qquad (15)$$

3.4 SYSTEM CIRCULATION RATE

It should be checked calculated initial circulation rate, whether its value is greater than circulation rate providing

minimum annular velocity. This minimum circulation rate is calculated from (16).

$$Qm = 0.041 * (Do^2 - Dp^2) * Vm \qquad ,gal/min \qquad (16)$$

Minimum annular velocity Vm is required to carring of cutting from the bottom of the hole to the surface. Recommended Hydraulic Practice (by Hughes Tool Co.) give the following table 3. Certain drilling condition such as high penetration rate, unusual hole conditions, etc., may suggest higher values. If the initial circulation rate is less than Qm it is necessary to use Qm value in the next steps of calculations. Otherwise the calculted initial circulation rate must be taken into the consideration.

TABLE 3

Hole Size inch	Annular Velocity ft/min
15	80
12 1/4	90
10 5/8	110
8 3/4	120
7 7/8	130
6	140

3.5 SIZING OF BIT NOZZLES

Using the formula for bit pressure drop (17) it is easy to determine total area of nozzles (18) and nozzles size (19).

$$Pb = Q^2 w/(12031 A^2 C^2) \qquad ,psi \qquad (17)$$

$$A = Q [w/(12031* Pb* 0.95^2)]^{(1/2)} \qquad ,sq.in. \qquad (18)$$

$$D = 32 [4A/3 pi]^{(1/2)} \qquad pi=3.1415 \qquad ,1/32 in. \qquad (19)$$

Diameter of every nozzle is calculated by routine which optimize feasible size selection.

3.6 PUMP CIRCULATION RATE

Total frequency of double acting duplex pump is given by term (20) but triplex pump - by term (21).

$$Fr = Q / \{0.0136 s [Ls^2 - (Rs/2)^2] Ef\} \qquad ,stk/min \qquad (20)$$

$$Fr = Q / [0.01 s Ls^2 Ef] \qquad ,str/min \qquad (21)$$

where: s - length of stroke, inch
Ls - diameter of liner, inch
Rs - diameter of piston rod, inch
Ef - volumetric efficiency of pump.

If total frequency exceeds max frequency of some applied pump then larger diameter of liner or multiplication of pumps should be considered. Since the mud pump is a source of discharge rate and pressure in circulating system a special attention should be payed on operational performance of it (fig.3).

To check whether the bit hydraulic horsepower provides necessary bottom hole cleaning and prevents hydraulic flounder ones may use the known diagram W*R vs BHHP (fig.4). An increase in product of weight on bit and rotational speed (W*R) gives a straight line increase in rate of penetration ROP until the flounder point is reached (fig.2). If rock cutting are not removed adequately from the hole bottom the bit is in flounder situation. Additional increase of W*R product produce non - linear characteristic. If BHHP at given bit size and W*R product is less than the diagram indicates the bit is operating in flounder region. When the BHHP is in excess of the value indicated on the diagram Smith Tool Inc. recommends to decrease pump input horsepower to save fuel and equipment wear.

4. SKETCH OF COMPUTER PROGRAM FOR SELECTION OF NOZZLE SIZE

There are different opinions by many experts on which is the best method to optimize hydraulics i.e. maximize BHHP or IF. Since there is not conclusive evidence that either of the method is best so it was assumed that both method shoud be available in the program.

Program starts with routine which allows to input data required to calculation. It was selected data which is falling into two categories:

- pump data i.e. max pump frequency, type of pump, liner size, rod size, stroke length, volumetric efficiency, max surface pressure;
- drilling system data i.e. mud weight, diameter of hole, inside diameter of casing, casing setting depth, minimum annular velosity, type of surface equipment, outside diameter of drilling pipe, inside diameter of drilling pipe, outside diameter of tool joint, inside diameter of tool joint, length of drill pipe string, outside diameter of hevi - wate pipe, inside diameter of hevi - wate pipe, length of hevi - wate pipe string, outside diameter of drill collars, inside diameter of drill collars, length of collar string, optimizing criterion.

This part of the program is prepared in dialogue manner which effectively eases user's burden.

Next block of program consists of statement which allows to reckon demanded total area of nozzles. Distribution of this area onto specific nozzles is optimized. There are considered two version of solution: bit with three and bit with two nozzles. Optimization criterion ratio based on minimized difference between demanded total area of nozzle and the sum of feasible nozzles area. Accuracy of program calculation is characterized by differential area given as output data.

Program is equipped with subroutine which allows to modify input data. This part of program has dialogue form. Service by this subroutine is initialized by negative answer on computer ask

for approval of finished series of calculation. Modification can take place for simple correction of some data or in case of necessity to change of full input data set (24 data). Modification subroutine is running in loop which is ended on distinct request of user.

It was thought of to simulate bit penetration progress in program. Assuming arbitrary step of progress equal 250 ft and max length of open hole equal 6000 ft it was reckoned data for BHHP and IF hydraulic optimization program ending each step by optionally printing protocol. Two random protocols are attached to this paper as example (fig.5 & fig.6). The 250 ft step in this simulation was assume as a depth which can be obtained in average circumstances with one bit trip. If it is required this value can be changed by substituting new value into program variable DE. While running of simulation of bit penetration progress, output data are calculated within three stages of drilling (fig.7). Stage a) is considered if open hole length is less than dril. collars length. In this case only part of drill collars is inside open hole and rest of drill string is inside casing. Stage b) is if the open hole length is less than sum of drill collars and hevi-wate pipe length and simultaneously greater than drill collars length. Stage c) is if total drill collars and hevi-wate pipe is inside open hole.

General sketch of program is depicted on program flow chart (fig.8). Compresed form of results calculated for presented paper is attached in table form (tab.4 & 5)and diagram (fig.9).

7. CONCLUSIONS

- Relationship between the nature of the bottm hole cleaning and bit hydraulic horsepower is however still not well understood further numerical computer aided studies of field and lab data should help to elucidate this problem.
- Experiences in application of presented in this paper approach of hydraulic program provide the certainty of its usefulness in field practice.
- At the first phase of 12.25" hole drilling and required increased annular velocity of 110 ft/min , fulfilment of BHHP criterion conditions requires running of two pumps within hydraulic system. In case of IF criterion above drilling conditions demand running of as many as three mud pumps. Thus in that conditions only BHHP criterion can be applied.

REFERENCES

1. Gatlin C.- Petroleum Engineering. Drilling & Well Completicns Prentace - Hall Inc. Englewood Cliffs, N.Y. 1960
2. Scott K. F. - A New Practical Approch To Rotary Drilling Hydraulics. SPE paper No 3530 - New Orleans, Louisiana 1971
3. Moore P.L. - Drilling Practices Manual. PPC Books. Tulsa 1974

TABLE 4

Hydraulic parameters at maximum hydraulic horsepower in bit criterion

Depth ft	Stand pipe pressure	Circ. rate GMP	Pump HHP HP	Bit HHP HP	Impact force lb	Nozzle sizes 1/32"	No pump	Pump frq
2000	3000	870	1693	990	2103	16,16,16	2	67
2500	3000	811	1577	922	1959	15.16.16	2	62
3000	3000	761	1481	866	1840	15,15,15	2	59
3500	3000	720	1400	819	1739	14,15,15	2	55
4000	3000	684	1331	778	1653	14,14,15	2	53
4500	3000	653	1270	743	1578	14,14,14	2	50
5000	3000	626	1217	712	1512	13,14,14	2	48
5500	3000	602	1170	684	1453	13,13,14	2	46
6000	3000	580	1128	660	1401	13,13,13	2	44
6500	3000	560	1089	637	1453	13,13,13	2	43
7000	3000	542	1055	617	1310	12,13,13	2	42
7500	3000	526	1023	598	1271	12,13,13	2	40
8000	3000	511	994	581	1234	12,12,13	2	39

Stand pipe pressure in psi; Pump frequency in str/min.

TABLE 5

Hydraulic paramiters at maximum impact force criterion.

Depth ft	Stand pipe pressure	Circ. rate GPM	Pump HHP HP	Bit HHP HP	Impact force lb	Nozzle sizes 1/32"	No pump	Pump frq
2000	3000	1077	2094	905	2236	18,20,20	3	55
2500	3000	1003	1951	843	2082	18,18,20	3	51
3000	3000	942	1832	791	1956	18,18,18	3	48
3500	3000	891	1732	748	1849	16,18,18	2	69
4000	3000	847	1646	711	1757	16,18,18	2	65
4500	3000	808	1572	679	1678	16,16,18	2	62
5000	3000	774	1506	651	1608	16,16,18	2	60
5500	3000	744	1448	625	1545	16,16,16	2	57
6000	3000	717	1395	603	1489	15,16,16	2	55
6500	3000	693	1348	582	1439	15,16,16	2	53
7000	3000	671	1305	564	1393	15,15,16	2	52
7500	3000	651	1266	547	1351	15,15,15	2	50
8000	3000	632	1229	531	1312	14,15,15	2	49

Stand pipe pressure in psi; Pump frequency in str/min.

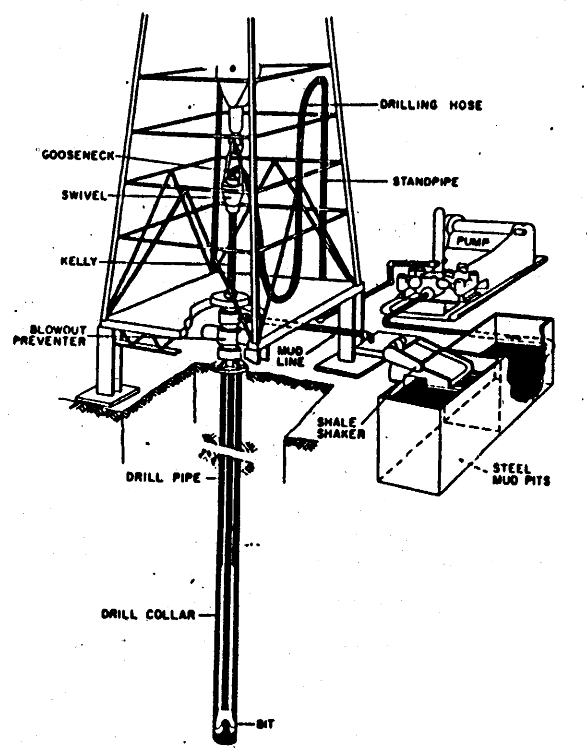


Fig.1. Hydraulic system sketch

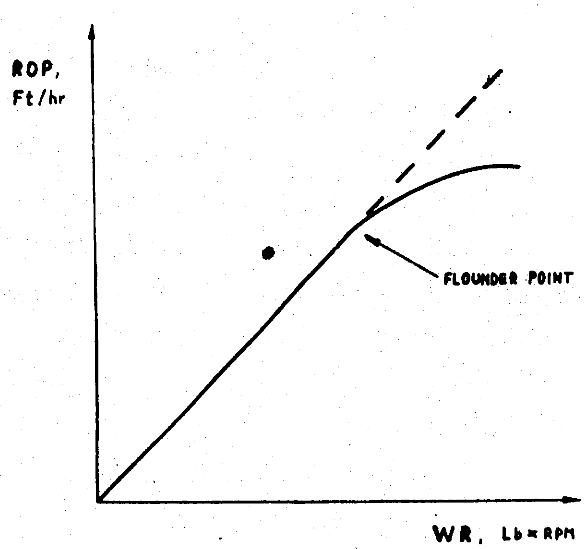


Fig.2, Diagram of rate of penetration ROP versus weight on the bit and rotational speed WxR product

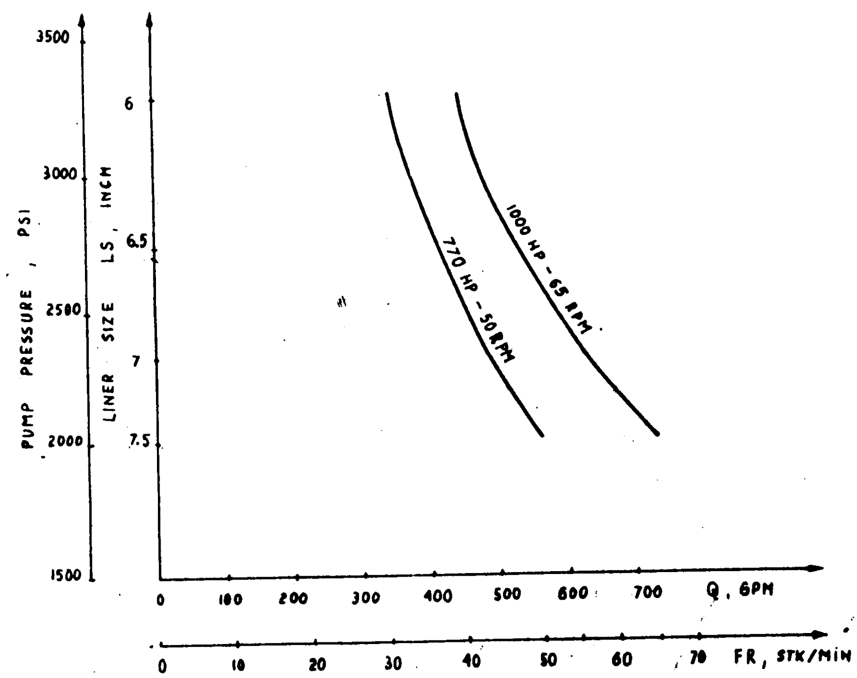


Fig.3. Pressure-output-horsepower diagram of duplex mud pump CM IDECO

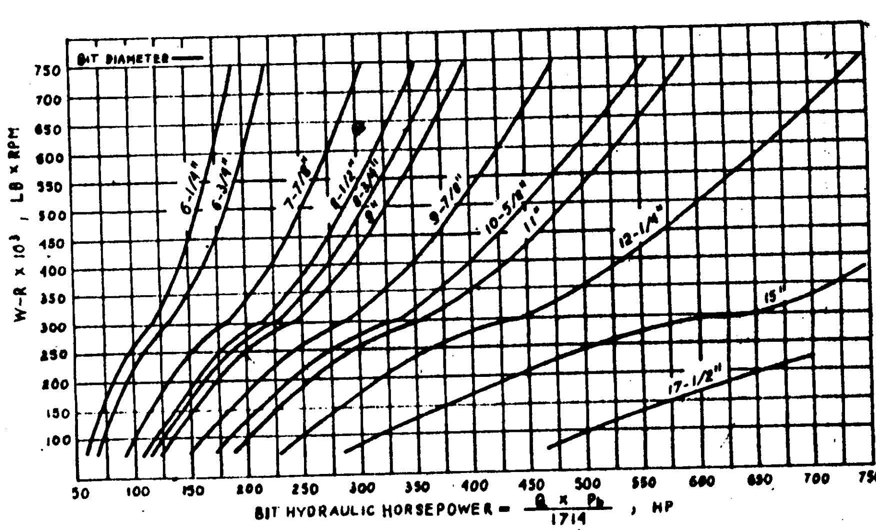


Fig.4. Chart of minimum BHHP versus WxR product to prevent hydraulic flounder

```
HYDRAULIC PROGRAM
*****************

INPUT DATA

MF= 70          LS= 6.25         RS= 3.5
S= 16           VE= .9           PSP= 3000
W= 10           DO= 12.25        DC= 12.515
CSD= 2000       VM= 110          CASE= 4
DP= 4.5         DPB= 3.826       DJ= 6.25
DJB= 3.25       LP= 1100         DHW= 4.5
DHB= 3          LH= 540          DC1= 9.5
DCB= 3.5        LC= 360          OPT= HHP
LO= 4000        TD= 6000

OUTPUT DATA

PRESSURE DROP ACROSS BIT
= 1950(PSI)

SYSTEM PRESSURE LOSS
= 1050(PSI)

HYDRAULIC HORSE POWER IN BIT
= 660(HP)

IMPACT FORCE               = 1401(LB)

CIRCULATION RATE           = 579.845(GPM)

NOZZLE AREA                = .3985(INCH SQR)

                NOZZLE SIZES
                ------------
13/32           13/32           13/32

DIFFERENTIAL AREA          = 9.628E-03(INCH SQR)
NUMBER OF PUPMS            = 2
PUMP FREQUENCY             = 44(STK/MIN)
PUMP HYDR. HORSE POWER     = 1127,67(HP)
```

Fig.5. Protocol of hydraulic program at maximum HHP in bit criterion

```
HYDRAULIC PROGRAM
*****************

INPUT DATA

MF= 70          LS= 6.25         RS= 3.5
S= 16           VE= .9           PSP= 3000
W= 10           DO= 12.25        DC= 12.515
CSD= 2000       VM= 110          CASE= 4
DP= 4.5         DPB= 3.826       DJ= 6.25
DJB= 3.25       LP= 1100         DHW= 4.5
DHB= 3          LH= 540          DC1= 9.5
DCB= 3.5        LC= 360          OPT= IF
LO= 4000        TD= 6000

OUTPUT DATA

PRESSURE DROP ACROSS BIT
= 1440(PSI)

SYSTEM PRESSURE LOSS
= 1560(PSI)

HYDRAULIC HORSE POWER IN BIT
= 603(HP)

IMPACT FORCE               = 1489(LB)

CIRCULATION RATE           = 717.382(GPM)

NOZZLE AREA                = .5737(INCH SQR)

                NOZZLE SIZES
                ------------
15/32           16/32           16/32

DIFFERENTIAL AREA          = 8.441E-03(INCH SQR)
NUMBER OF PUMPS            = 2
PUMP FREQUENCY             = 55(STK/MIN)
PUMP HYDR. HORSE POWER     = 1395,14(HP)
```

Fig.6. Protocol of hydraulic program at maximum IF criterion

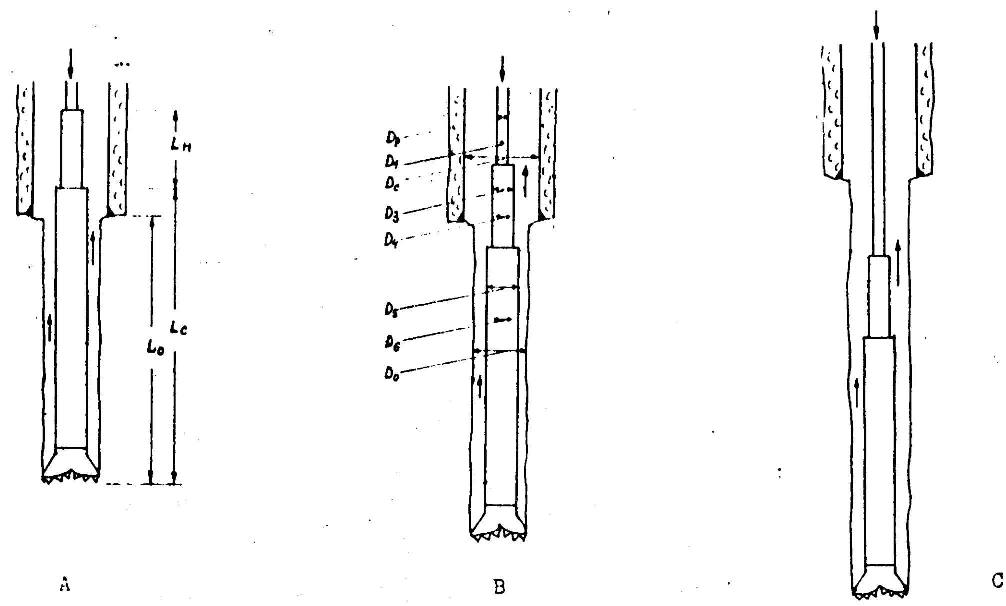


Fig.7. Scheme of hydraulic system in the hole

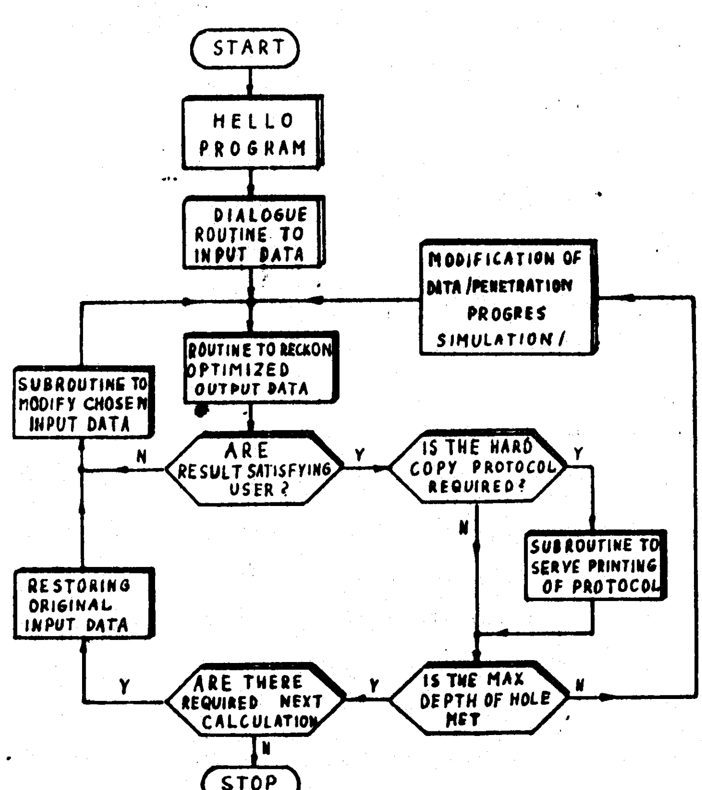


Fig.8. General program flowchart

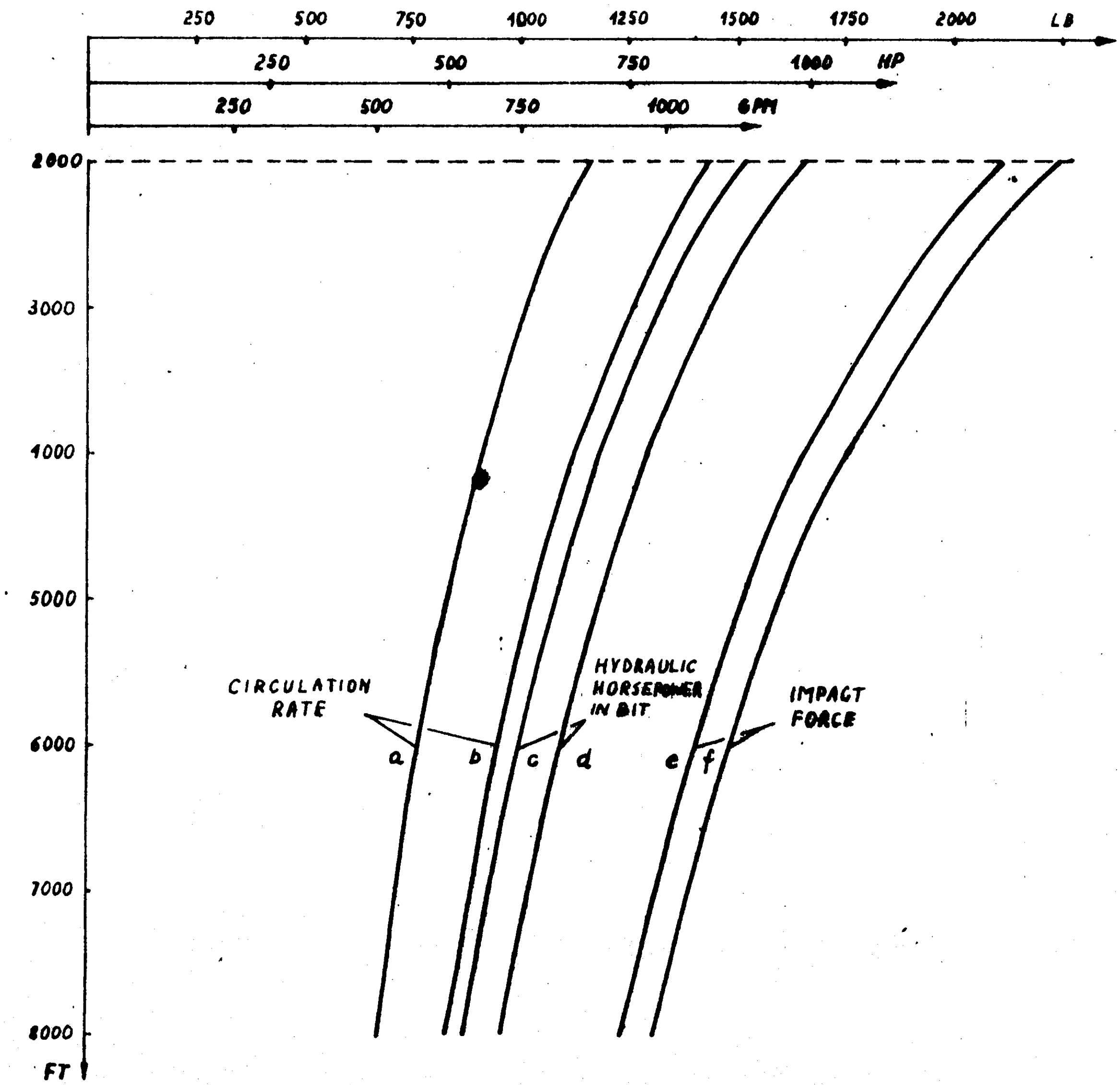


Fig.9. Circulation rate, hydraulic horsepower in bit and impact force versus depth at maximum hydraulic horsepower in bit criterion /a,d,e/ and at maximum impact force criterion /b,c,f/

ESTIMATION OF RECOVERY EFFICIENCY OF LIBYAN CARBONATE OIL RESERVOIRS

A. Y. ZEKRI/M. S. NASAR

AL FATEH UNIVERSITY

1. ABSTRACT

Estimation of recovery efficiency of any newly discovered reservoir is an important piece of information needed to assess the economical viability of that reservoir. Therefore, it is essential to be able to predict as accurately as possible the reservoir reserves based on limited data available on hand for newly discovered reservoirs.

In this study, data collected from forty Libyan oil reservoirs were utilised to generate a correlation between reservoir future recovery efficiency and basic reservoir data of porosity, permeability, saturation, oil viscosity and net formation thickness. This correlation will provide a useful tool for any engineer dealing with carbonate oil reservoirs to predict with more confidence its recovery efficiency after drilling a wildcat well and collect limited data.

2. INTRODUCTION

Our current life has been influenced by oil and gas more than any other natural resource, and indications are that oil and gas reserves will increase in importance in the remainder of this century. Oil and gas provides an inexpensive source of energy.

Reserve estimates have dictated actions of different Governments entire industries, individual companies and lending institutions. Many people working in the petroleum industry, especially petroleum engineers spend a major part of their professional lives developing estimates of reserves together with new methods and techniques for improving these estimates. The confidence levels and the technique utilised by the petroleum engineer depend on the quantity, reliability and the maturity of the data available. The data quality, therefore, indicate the confidence one should have in the reserve estimates.

There are various methods used by the oil industry to estimate recovery efficiency such as analogy, volumetric calculations and performance techniques (numerical simulation models, material balance and decline curve analysis).

Before a reservoir is drilled, prospective reserves are usually estimated on the basis of analogy. On the other hand, if little or no production from the target formation exists, then statistical data from wells completed in the formation is used to predict the recovery efficiency of that reservoir. When performing a statistical analysis for prediction purposes, a simple average of various rock and fluid data needed to be employed in the technique is normally required.

By searching the literature regarding recovery efficiency estimate based on limited rock and fluid data obtained from a newly discovered oil field, one notices limited work has been done. In a reservoir study made by Craze & Buckley[1], 70 of 103 fields analysed produced wholly or partially by water-drive conditions.

Arps[2] indicated that data obviously is related to the reservoir oil viscosity and permeability. He obtained average correlation between oil viscosity and oil residual saturation, and took into consideration another variable, reservoir permeability.

Guthrie & Greenberger[3] conducted a statistical study using multiple correlation analysis methods. They found a correlation between water-drive recovery and five variables, permeability, saturation, viscosity, porosity and net formation thickness for water-drive sandstone reservoirs. They indicated that 50 percent of the fields had recoveries within ± 6.2 percent of the predicted recovery by the correlation. This correlation is used extensively for sandstone or carbonate reservoirs to obtain a rough estimate of recovery efficiency despite its limitations.

Since most of the Libyan oil reservoirs and Middle East oil reservoirs are of carbonate type (limestone and dolomite type of lithology), it is essential to utilise data from fields representing Libyan reservoirs. In this study data from 89 carbonate and sandstone Libyan reservoirs were employed to try to develop different correlations between recovery factor and various fluid and rock data. Most useful correlation developed using multiple regression analysis for water-drive carbonate reservoir was 40 Libyan reservoirs data representing different carbonate horizons with water influx mechanism.

Results indicate that 0.113 standard deviation exists in this type of reservoir. Meanwhile, if only reservoirs with recovery factors of 20 percent or higher are used, we observe improvement in correlation results. A substantial reduction in standard deviation from 0.113 to 0.079 percent is observed, i.e. a more reliable correlation.

3. DISCUSSION

Reserve estimates are just those estimates which can be no better than the data on which they are based and are subjected to the experience of the estimator. Unfortunately, reliable reserve figures are most needed during the early stages of a project, when only a minimum amount of information is available. As the field is put on production, more data and information becomes available. As the project matures, this increase in data with which to work changes the method or methods used to predict the recovery efficiency and improves the confidence in the reserves estimates. Recovery efficiency is estimated during various stages of oil reservoir life. These stages are before drilling or any subsurface development, after drilling a few wells, before producing the reservoir, after some performance information is available and after performance trends are well established. In this study, the main period of the life of the reservoir in recovery efficiency could be estimated after drilling a few wells and before producing the reservoir.

Various types of reservoirs were analysed to develop a correlation between recovery efficiency and various fluid and rock properties, porosity, permeability, saturation and viscosity. The main correlation developed for water-drive carbonate oil reservoirs were data from 40 Libyan oil reservoirs, see Table 1, utilised to develop the correlation. The empirical correlation obtained was:

$$\text{Recovery factor} = 0.0554 + 0.6065 \text{ porosity} + 0.0955 \log\left(\frac{K}{\mu}\right) - 0.0571\, S_w - 0.0426 \log H$$

As shown in Fig. 1 data is scattered mostly below the chosen line for recovery factor of 20% or higher and above the line for points with recovery factor below 20% with a standard deviation of 0.114. Therefore, elimination of data points of RF below 20% were tested and results were plotted in Fig. 2. As shown in Fig. 2, more fair distribution of data was obtained with a standard deviation of 0.079. The correlation between oil recovery and various data for water-drive carbonate reservoirs with RF greater than 20% is:

$$RF = 0.3251 - 0.1287 \text{ porosity} + 0.0745 \log\left(\frac{K}{\mu}\right) - 0.046\, S_w - 0.0433 \log H$$

Another correlation was obtained for solution gas drive carbonate-oil reservoirs. Data from only 7 Libyan reservoirs were utilised, with the following result:

$$RF = 0.3514 - 1.1967 \text{ porosity} + 0.00955 \log\left(\frac{K}{\mu}\right) + 0.0205\, S_w - 0.0434 \log H$$

With standard deviation of 0.035, due to limited data used in the correlation, not much confidence is given to this result, (see Fig. 3 , and Table 2.)

From the analysis of data from 9 Libyan carbonate oil reservoirs with water injection, see Table 3, the following correlation was obtained, where standard deviation is 0.073.

$$RF = -0.2224 + 0.1262 \log\left(\frac{K}{\mu}\right) - 0.0163\, S_w + 0.1722 \log H$$

Again, not much confidence is given to this correlation due to limited data used (Fig. 4).

The effect of using limited data, i.e. no pay thickness was utilised in the analysis, was also examined for the case of water-drive carbonate reservoirs and the following empirical correlation was obtained.

$$RF = -0.0358 + 0.6603 \text{ porosity} + 0.0957 \log\left(\frac{K}{\mu}\right) - 0.0304\, S_w$$

With standard deviation of 0.113, the data and the distribution of the results are presented in Table 1 and figure (5) respectively.

4. CONCLUSIONS

1. A new correlation for Libyan carbonate oil reservoirs to estimate RF using limited data was developed.

2. This correlation could be used in estimating the oil recovery factor for all newly discovered Middle East water-drive carbonate oil reservoirs.

3. A correlation for solution-gas drive carbonate oil reservoirs was obtained to be used as a rough estimate of RF.

4. Libyan sandstone water-drive reservoirs correlation was also developed.

5. ACKNOWLEDGEMENT

The authors would like to thank all Libyan Oil Companies and NOC Production Department for providing the data used in this study and for their permission to publish this work. Many thanks to Waha Oil Company for their permission to use their computer facilities. Also we would like to state our appreciation to Anne Harriss for typing this paper.

6. REFERENCES

1. R.C. Craze & S.E. Buckley, "Actual Analysis of the Effect of Well Spacing on Oil Recovery", Drilling and Production Practice, API (1945), pp 144-155.

2. J.J. Arps, "Estimation of Primary Oil Reserves", Trans. AIME(1956) 207, 183-186.

3. R.K. Guthrie and Martin K. Greenburger, "The Use of Multiple Correlation Analysis for Interpreting Petroleum-Engineering Data", Drilling and Production Practice, API (1955), pp 135-137.

4. F.A. Garb, "Oil and Gas Reserves Classification Estimation and Evaluation", Journal of Petroleum Technology, March, 1985, pp 373-390.

5. "World Petroleum Congress Study Yields Reserves Classification", Oil and Gas Journal (Nov 21, 1983).

6. "Proven Reserves Definition", Journal of Petroleum Technology, Nov 1981, 2113-14.

7. Petroleum Engineering and Production Handbook, T.C. Frickem McGraw-Hill Book Co. Inc., New York City (1962) Vol II, Chapters 37 and 38.

TABLE 1

WATER DRIVE - CARBONATE RESERVOIRS DATA

					Reported		Empirical	Without h
FIELD	POR frac.	K md	U cp	Sw frac.	h ft.	RF frac.	RF frac.	RF frac.
Ali NC29B	0.230	90.0	0.650	0.460	37.0	0.480	0.306	0.307
Almas NC29C	0.236	16.0	0.580	0.455	58.0	0.490	0.235	0.244
Intisar 103E	0.190	190.0	1.100	0.440	17.0	0.200	0.307	0.290
103D Elgiza	0.266	43.0	3.200	0.287	30.0	0.270	0.245	0.239
Intisar 103B	0.200	490.0	0.024	0.230	33.0	0.49	0.510	0.502
Sabah Beda C(I)	0.241	353.0	0.800	0.185	36.2	0.491	0.377	0.371
Sabah Beda C(II)	0.272	353.0	0.800	0.354	26.3	0.491	0.392	0.386
W.Sabah BedaC(I)	0.206	200.0	0.800	0.236	33.0	0.302	0.331	0.322
W.Sabah " (II)	0.203	100.0	0.800	0.494	44.0	0.302	0.281	0.284
E.Sabah Bedac	0.182	200.0	0.800	0.197	29.5	0.131	0.321	0.308
Elgiza E & W	0.260	150.0	1.400	0.430	32.0	0.350	0.318	0.317
Gialo	0.222	153.0	3.080	0.310	98.0	0.377	0.249	0.264
Choboc (Kalash)	0.388	520.0	0.540	0.450	27.3	0.300	0.489	0.492
Tagrifet(Farrud)	0.250	35.0	2.030	0.270	35.0	0.120	0.244	0.239
Farrud(Mabruk)	0.246	145.0	0.790	0.450	38.0	0.375	0.328	0.330
Bouri	0.150	300.0	3.490	0.200	500.0	0.150	0.204	0.242
Ed Dib(Gir/Fach)	0.240	100.0	0.700	0.350	85.0	0.150	0.304	0.318
Um-Farroud	0.240	40.0	0.700	0.270	38.0	0.330	0.286	0.283
Field 4Z DOL	0.240	40.0	2.600	0.270	38.0	0.148	0.231	0.228
BuMras(Mabruk)LS	0.260	340.0	13.000	0.450	7.4	0.391	0.286	0.258
Daba(Farr UD)	0.220	45.0	1.650	0.570	53.0	0.200	0.220	0.230
Facha(Mabruk)	0.250	23.0	0.940	0.770	24.0	0.140	0.240	0.242
103E Elgiza B	0.050	250.0	6.500	0.500	49.0	0.040	0.136	0.134
103E Elgiza A	0.268	370.0	6.500	0.410	18.6	0.060	0.308	0.297
103E Gir B	0.246	200.0	1.700	0.311	30.8	0.304	0.321	0.315
103E Gir A	0.245	16.0	1.700	0.300	56.0	0.233	0.205	0.210
Bahi PL7 LS	0.280	150.0	0.700	0.445	103.2	0.400	0.336	0.359
Bahra PL7 LS	0.301	34.5	1.230	0.448	28.8	0.330	0.288	0.288
Nasser	0.186	5000.0	0.880	0.220	122.0	0.461	0.425	0.440
Gialo	0.200	45.0	3.000	0.520	18.0	0.099	0.206	0.193
"Paleocene LS	0.252	14.5	0.670	0.301	49.6	0.340	0.246	0.249
"4B Paleocene	0.195	400.0	0.840	0.555	85.0	0.300	0.320	0.332
Barash P'cene LS	0.200	388.0	1.190	0.471	16.6	0.450	0.338	0.322
Kasrab P BaselD	0.237	27.1	2.400	0.440	29.0	0.300	0.212	0.208
Warid Field	0.220	2.0	3.700	0.500	40.0	0.034	0.066	0.069
Beda Field	0.200	60.0	2.800	0.500	60.0	0.300	0.199	0.208
Kotla Field	0.220	60.0	2.000	0.350	150.0	0.130	0.217	0.240
Umm-Faroud	0.240	40.0	0.700	0.270	38.0	0.330	0.286	0.283
Facha(Gir) Dol	0.240	25.0	1.400	0.330	42.0	0.140	0.232	0.232

Emperical Recovery Factor, including h, fraction

$=0.0554+ 0.6065(\text{porosity}) + .0954(\log (k/\mu)-0.0571(Sw)-0.0436(\log(h))$

Standard Deviation = 0.114

Emperical Recovery Factor, without h, fraction

$=-0.0358+0.6603(\text{porosity})+0.0957 (\log(k/\mu)) - 0.0304 (Sw)$

Standard Deviation = 0.113

TABLE 2

SOLUTION GAS DRIVE - CARBONATE RESERVOIR DATA

FIELD	POR frac.	K md	U cp	Sw frac.	h ft	Reported RF frac.	Emperical RF frac.
Hofra(Thalita)	0.170	6.0	0.580	0.330	32.0	0.150	0.186
Dahra B	0.330	150.0	0.630	0.420	17.6	0.100	0.138
Mellugh (Facha)	0.250	25.0	0.354	0.390	25.0	0.250	0.176
Defa LS	0.160	3.2	1.600	0.320	94.0	0.112	0.110
AA Area LS	0.244	14.7	1.200	0.400	27.7	0.100	0.109
Hofra - Dahra B	0.320	25.0	0.620	0.360	14.2	0.100	0.079
Hofra Dahra B&Mabruk	0.330	150.0	0.600	0.420	17.6	0.125	0.140

Emperical Recovery Factor, frac.

$$= .3514-1.1967(\text{porosity}) + .00955\ (\log\ (k/\mu)\ ) + .0205(Sw)-.0434(\log(h)$$

Standard Deviation = 0.035

TABLE 3

WATER INJECTION - CARBONATE RESERVOIR DATA

FIELD	POR frac.	K md	U cp	Sw frac.	h ft	Reported RF frac.	Emperical RF frac.
Intisar C103 Reef	0.220	85.0	0.560	0.494	141.0	0.550	0.414
Intisar A103 Reef	0.198	18.0	0.160	0.113	648.0	0.472	0.518
Zella NC74B Facha	0.195	7.7	0.176	0.199	117.0	0.350	0.338
Fidaa Facha	0.209	125.0	0.970	0.370	67.0	0.300	0.343
North Hakim Facha	0.204	14.0	0.150	0.222	29.0	0.300	0.276
South Hakim Facha	0.216	27.0	0.420	0.251	46.0	0.300	0.285
Gham Farrud	0.250	50.0	0.400	0.250	50.0	0.300	0.328
Gham Farrud	0.270	50.0	0.400	0.250	55.0	0.300	0.335
Zeuad	0.270	50.0	0.400	0.250	55.0	0.300	0.335

Emperical Recovery Factor, frac.

$$= 0.2224 - .1262\ (\log\ (k/\mu) - 0.0163\ (Sw) + 0.1722\ (\log\ (h)\ )$$

Standard Deviation = 0.073

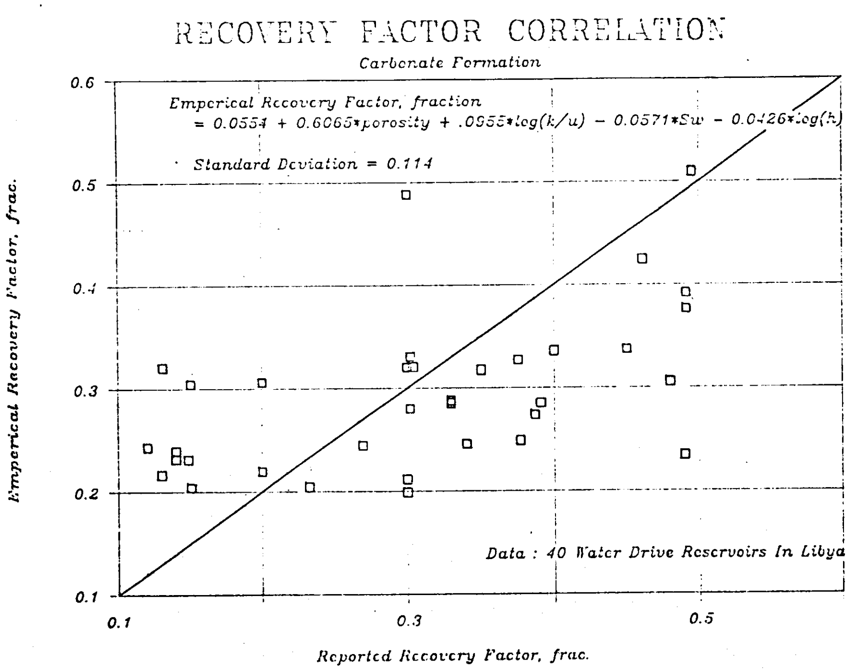


Fig.1 Relationship between Emperical and Reported Recovery Factors for Carbonate Formation - Water Drive Reservoirs

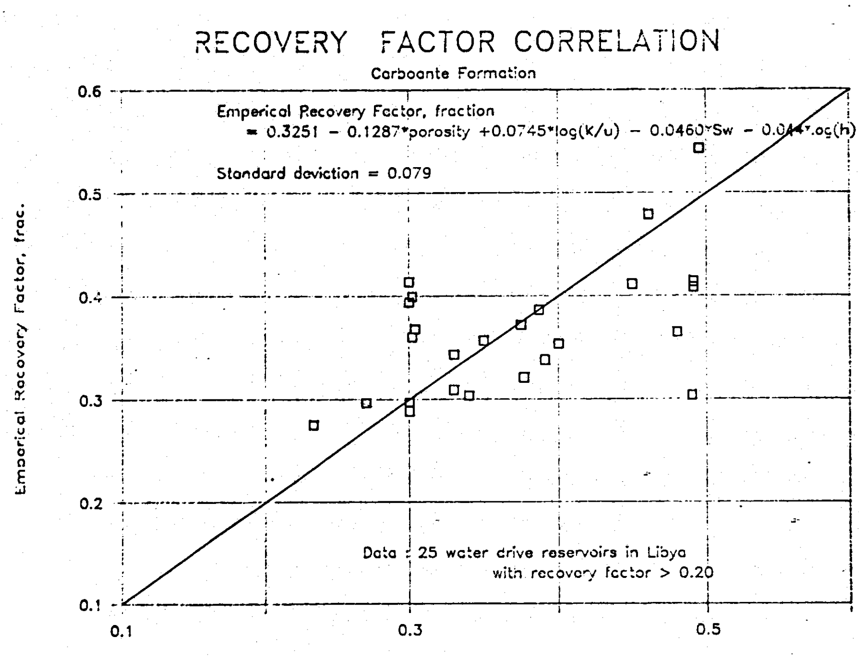


Fig.2 Relationship between Emperical and Reported Recovery Factors for Carbonate Formation - Water Drive Reservoirs

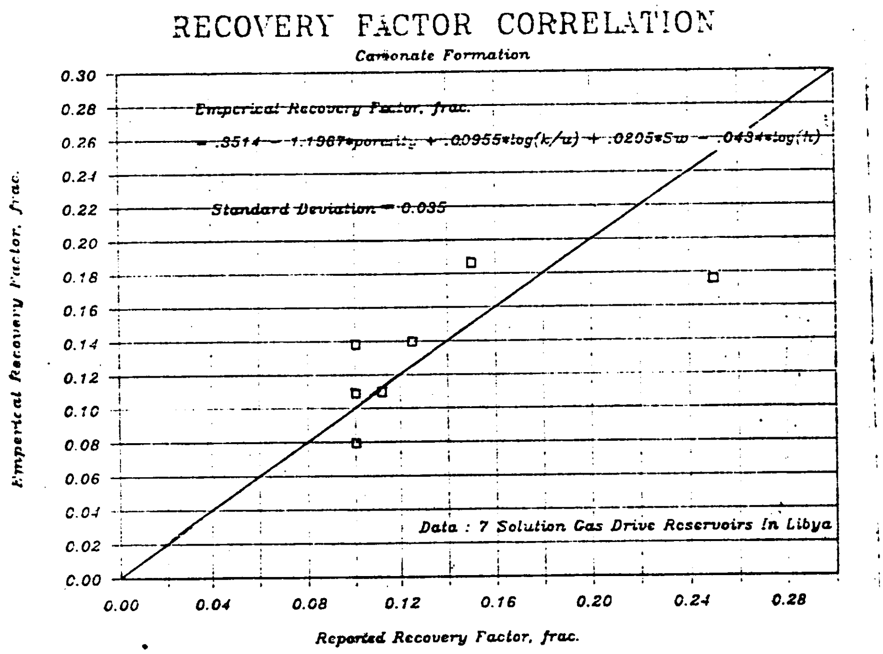


Fig. 3 Relationship between Emperical and Reported Recovery Factors for Carbonate Formation - Solution Gas Drive Reservoirs

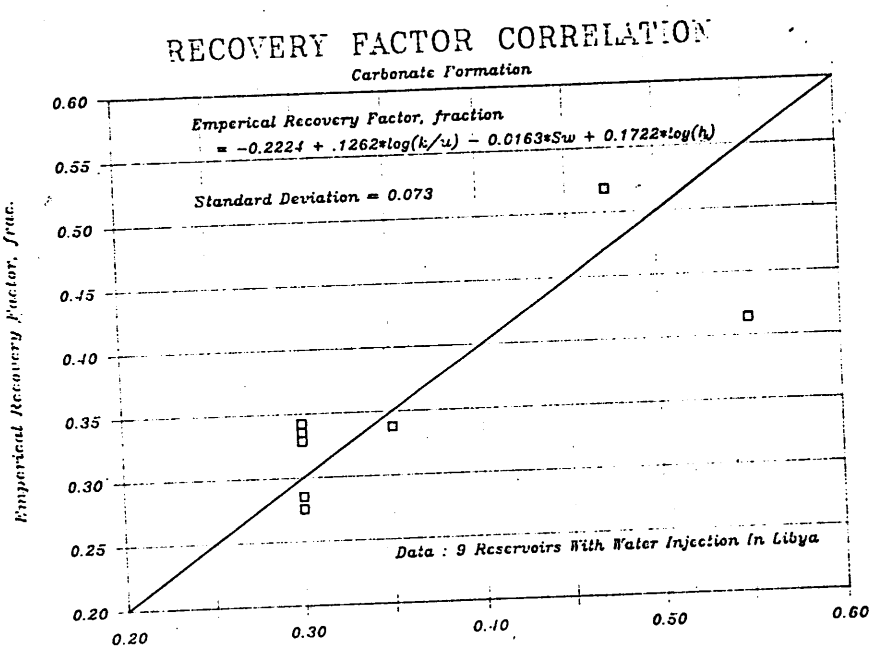


Fig. 4 Relationship between Emperical and Reported Recovery Factors for Carbonate Formation - Water Injection Reservoirs.

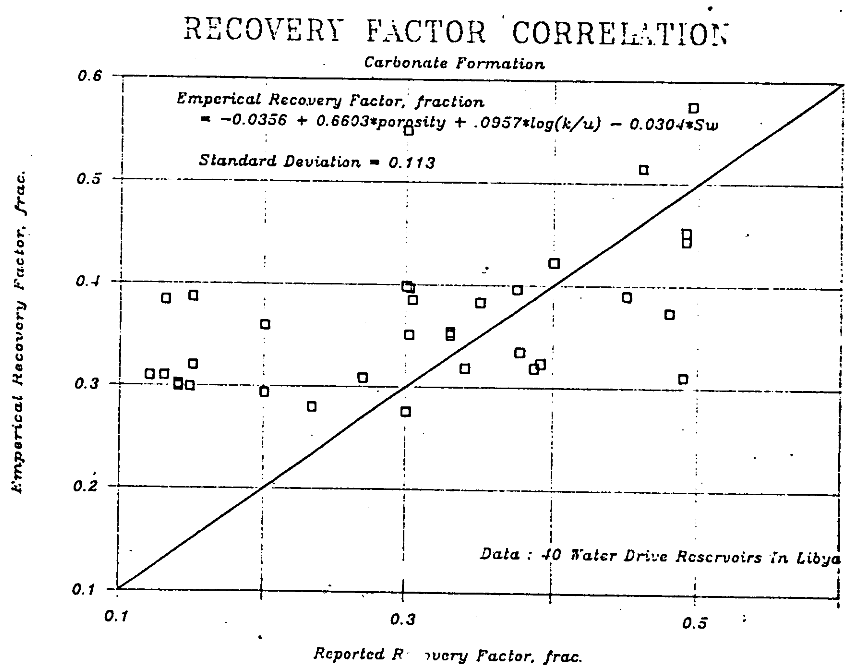


Fig. 5 Relationship between Emperical and Reported Recovery Factors for Carbonate Formation - Water Drive Reservoirs excluding Pay Thickness

SEARCHING FOR OIL WITH ELECTRONIC MACHINE

A.B.Kieres
Intelligent Systems Laboratory
Department of Computer Engineering
Engineering Research Centre
Ar-Raya Al-Khadra University
Tripoli, G.S.P.L.A.J.

ABSTRACT

Oil prospecting is a highly skilful science undertaken with the use of modern electronic devices. Review is made of such equipment particulary application of computers.

1. INTRODUCTION

1.1 Petroleum Accumulations

Mineral oil deposits occur deep under the surface of the Earth and were formed during millions of years from the tiny marine creatures and plants that lived in the sea water and later sank into the mud at the bottom. With time the pressure of the sea water compressed the mud containing the oil into a bed of sand or lime rocks. Such rocks held oil and its gas like a sponge. Then the harder rocks pushed down the oil and gas. In this way such deposits were trapped. However because the Earth changed its image the oil deposits did not stay in places where they were formed.[1]

1.2 Prospecting for Oil Previously

It may be quite difficult to find oil but as it is the world's most important source of energy [2] it is searched for. The below description of the various stages of the oil prospecting has been made according to the publication [1] from 1964.

1.2.1 Airphotographs and a topological map

To start, firstly detailed airphotographs of the new area are required. They are examined in detail, to find out for example different colour of sand. If it is darker than the rest of sand it indicates that there is rock underneath. Such aerial photographs are studied with a stereoscope, which helps to make a topological map to be used in the field work.

1.2.2 Survey in fields

(i) A general survey for any oil seepages on the surface and any types of rocks associated with the oil is done in the field on foot. The cliffs and mountains are climbed in order to get some idea about the rock formation below. Such examinations give basis for preparing detailed geological map of the area. Also samples of rocks are taken for careful microscopic inspection in special laboratories to find any trace of fossils of plants and animals from which the oil is formed.

(ii) In case of such a finding the geophysicists start making their surveys which include checking upon the deep rocks under the ground.To discover the traps of oil various instruments are used. The gravimeter measures the irregularities in gravities of the various rocks. The magnetometer finds the differences in magnetism of the different rocks. But the most important is the seisometer which records the sound waves from the rocks below, between which the dynamite is placed and exploded.

So with the help of these instruments the different traps can be identified, and their depth established.

(iii) Prospecting for oil under water is more or less the same as on the land but the techniques used are different. The samples of rocks are usually brought up by the divers who may be sent down with breating equipment and sometimes in cages to be protected from the sharks. Also underwater photographs are taken to help geologists with their analysis. Similary, as on land an artificial earthquake is created to record the shock waves on a seismograph towed on a cable and upon that construct of the likely deep under the sea-bed laying rock constructions is made.

(iv) Supported by these findings, conclusions and recommendations are made. They include considerations upon whether or not deposits are big enough to be worth bringing them up.

1.2.3 Exploratory drilling

Then the exploratory drilling of well is made in order to establish whether indeed there is an oil in the recommended place.

(i) Drilling is a very risky and hazardous operation as the drilling bit cannot be seen inside the hole by operators. It must be very carefully planned and supervised in order to avoid for example a blow-out which may be caused for instance by a broken piece of equipment inside the well.

The rotary table is placed on the derrick floor above the well. Through its center the drilling bit is pushing downwards to cut into the rock. As the drilling operation progresses the drill pipe is regulary lengthened. A driller with his crew works on a drilling.

He controls the weight of the string pushing down on to the bit and its speed. If needed the bit is changed by pulling the drilling string out of the well with the hoisting equipment in the derrick.

A mixture of liquid clay, mud, and chemicals is pumped down inside of the hollow drilling string. It cools the bit and delivers outside the small pieces of rock resulting from the bit operation. The cuttings and the drilling mixture on returning to the surface are checked upon to ascertain whether it contains the water, oil and gas. Such examination takes place outside the bore or in the special laboratories and it gives information about rock formation under the surface.

(ii) Geological tests are conducted all the time during exploratory drilling to forcast the possible difficulties and dangers and to ensure that the whole operation is economical one.

In order "to see" inside the well the measuring instruments are lowered into well. This operation is known as logging. During drilling the walls of well are strengthened with casing.
When oil is discovered then the drilling tools are replaced by a long pipe inside the bored hole to take out the oil and gas in the production process.[1]

1.3 Aim of Study

This paper aims to show electronic equipment engaged in oil prospecting. By the electronic machine indicated in the title it is understood the modern electronic equipment, electronic instruments, particularly computer, and robot with both firmware and software. They are viewed along the stages of searching for oil which include drilling of exploratory well.

2. ANALYSIS

2.1 Preliminary Considerations

Nowadays even before taking into account the particular area several kinds of preliminary studies can be conducted in respect of already existing data refering to such area.

2.1.1 Data Bases

Regional geological, geophysical surveys, discoveries of some oil, exploratory and development wells, offshore fixed structures, availability of concession, statistical file of prospecting, production of well activity, cartographic information can be provided for access on mainframe and personal computer (PC).[3] The interactive exploration systems exist.[4]

2.1.2 Topographic survey, and Satellite-based Natural Resources Discovery (NRD)

The topographic survey of a seabed shows peaks and troughs on the seafloor. It is completely automatic and supported by DB. [5]
Also NRD system can assist. It assumes that gravity and enviromental forces are shaping the surface of the ocean. Computers are used for taking off waves, tides, water depths in the presented to them images. And then the prospective resource places are found by mapping the ocean with the satellite measurements. [6]

2.1.3 Aerial Survey

Aerial survey takes place over the selected area and it gives as the result not only the airphotos but also the aerial micromagnetics, airborne hydrocarbon gas sensing, aerial gamma-ray spectrometer. Aeromagnetic data can be collected simultaneously with gamma-ray spectrometer coverage. Irregularities of micromagnetic presumably due to petroleum diagenetic effects can be recorded. Detection of the appearance of hydrocarbon gases coming out from the Earth is made by the helicopter-borne sensor system.

However the all obvious irregularities of the aerial micromagnetics should be checked on the ground where also truck-borne gamma-ray spectrometer survey and seismic waves recording on a seismogram are carried on. [7], [8]

2.1.4 Computers in designing of seismic equipment, recording and analysing of underground data

(i) The computers (Computer Aided Design - CAD) are used in design of seismic vessels [6] from which the microprocessors controlled seismograph is deployed on the shore or to an ocean-bottom. This device records geophysical data. [9], [10]

(ii) The electronic processing techniques such as creating data spikes, stacking and predictive deconvolution may improve seismic analysis.
Computer handling of seismic data with additional information makes a parametric model for picturing reservoir stratigraphy or for exploration. [6] The seismically measurable parameters such as clay content, soil gas hydrocarbon analyses for the presence of hydro-carbon and so forth are subject of laboratory studies with assistance of mass spectrometry and computer. [11] [12]

In the area of petroleum reservoir, computer simulation is used for variety of production and injection well constrains. [13]

(iii) The process of hydraulic fracturing is modelled. [14], [15]

2.1.5 Diver control system

Diver control system controls of the divers' air supply, communication, and can monitor the divers depth. It is with voice instructions given to divers. [5]

2.1.6 Underwater robot

There is information about the development of automatic electronic machine to be used in underwater exploration of petroleum.[16]

2.2 Exploration Drilling

To make sure that there is oil in the indicated place, the exploration drilling has to be made.

2.2.1 Information on wells

Previously made information on wells and formations can be available on computer. It includes petrophysical data such as logs, cores, well test, sampling and analysis, equipment and operation[17],[18], and also data about individuals directly connected with or engaged in, oil and gas exploration or drilling.[3]

2.2.2 Well completion

(i) Computer Aided Engineering (CAE) offers techniques of well completion including spacing of wells, perforation, tubing, casing, stimulation, dimension of well.[19]

(ii) Electronics and computer systems are used for dynamic positioning of mobile rigs such as drill ships and semi-submersibles.[10] When working over subsea completions from dynamically positioned service vessels operating in the seas a winch must be deployable. The electronic packages indicate weight, depth, speed, direction control, line tension. The maintenance of the underwater sytem of disperse holes is microprocessor based. It includes downhole safety valve replacement and gathering of reservoir data.[20]

(iii) Microprocessors, DB and Artificial Intelligence (AI) participate in a remote-controlled, self-propelled miner system. A fully automatic position control which can be changed to a manual, manoeuvres the ship, the mining pipe and the seafloor miner in the offshore.[21]

(iv) The compact automated supervisory system is available for rotating machinery.[22],[23] The modular software package which receives information on current system operation evaluates equipment parameters such as motor characteristics, finds out the best system operating conditions and passes the results to system control devices or operators.[24]

(v) The well requires reinforcing which can be done with cement. Before doing such job physically the computer program from the given input such as hole size, casing program, mud and water weight, cement can calculate key job parameters and generate gradual procedure for cementing.[3] Coating thickness can be tested.[23] Then postevaluating with a cementing simulator can be done.

It collects the actual job performance data such as fluid properties, changing displacement and mud return rates, free-fall effect, well geometry and comparison with the predicted cementing performance is being made. Such similator can be used in designing cementing operations and in monitoring the actual jobs.[25]

(vi) Prediction of corrosion[3], the volumes of oil and gas that will be ejected from a blowing well can be made on computer.[15],[26]

(vii) The disposal of drill cuttings is done with the aid of a computer.[26],[27]

2.2.3 Electronic orientation measurements and further computer usage in well

The developments in computer simulation and electronic orientation measurements are of use in exploration drilling.

(i) In the measure downhole model, an in-the-probe computer that corrects for temperature and pressure is engaged.[3] A density dipmeter gives dipdata in oil- or water-based muds.[28] Flow, pressure, temperature, fluid density can be concurrently recorded.[26] The actual drilling angle is controlled and adjusted by electronic equipment.[9],[18] The instruments and systems exist which automatically (in laboratory or in dangerous areas) on-line [28] continuously sample of petroleum distillates and report. [24],[11]

Also software can calculate flowing pressure, temperature, liquid holdup, density, velocities, and flow patterns for any petroleum that flows in wells.[3],[29] A programmed PC totally controls the automated operation. The comparisons versus previous calibrations can be displayed on the PC screen.[23] All these measurements can be remote communicated.[3],[8]
On PC the local faults would be mapped by using the most recent multitude of measurements and Vertical Profiling (VSP).[8]

(ii) The data acquisition system of the modern logging system consists of the sensors which record and monitor to the surface. For example flowmeter can reveal wellbore cross -flow in multilayered reservoirs.
The obtained data can be stored or processed instantly to form merged logs, crossplots, listing without stopping or interrupting of taking probes by on-site computer. An intelligent display shows results.[26],[3]

Program package for cased-hole and open-hole data analysis can be used for log interpretations. Such drilling parameters as formation hardness, permeability, and fracturing extent are electronically recorded. This software continuously monitors these rock conditions while drilling so that a driller is notified before hand about any drilling abnormalities, extensive rotation speed.

Therefore a driller can react accordingly.[3],[30]

The software exists that provides access to seismic, geological and well-logging data at the same computer work station. [25],[26] Also cementing, logging and completion can be presented on flow profile program.[31]

(iii) There is scientific spreadsheet for postaquisition well data analysis and display.[3]

2.2.4 Software programs for training

The operators are trained on the computer simulator so that they know how to respond to emergencies and various disturbances,[24] as for example blow-outs.[28] Also simulator packages for diving exist. [3],[21] For drilling professionals computerised knowledge, engineering programs covering hydraulics, mud engineering, well planning, cementing, pressure detection, directional drilling and optimisation are proposed.[3]

2.3 Expert Systems

Last but not least are mentioned some AI systems which are either experimental or practical on various levels of complexity and which applied to oil prospecting. They can be used on computers.[32],[33] EXPERT used in oil exploration helps to design and test consultation models, WAVES advises on seismic data analysis for oil industry, DRILLING ADVISOR opinions on oil well drilling problems and proposes corrective steps, DIPMETER ADVISOR assists with oil-well analysis.[34] [35]

3. CONCLUSIONS

The paper describes various stages of exploration for oil a quarter of century ago. At that time a lot of manual work was involved in it. Then it presents current prospecting for oil with the use of modern technology. It has been shown that an electronic machine is recording, analysing relevant information and conducting unmanned drilling operation. The PC is becoming a standard tool for extrapolation of detailed petrophysical data even large distances from wells and also for access to seismic, geologic and well-logging data.

However in searching for oil acquisition of data requires the expertise of geologists and geophysicists and therefore still cannot be automated.

Harsh environmental conditions such as for example the depth of the sea pushed forwards the development of automatic electronic machine to be used in exploration of petroleum. The unmanned stations already have existed. They can be remotely controlled, for example from the special base boat.

In future more electronic machines with "intelligent behaviour" are expected to be engaged in searching for mineral oil.

4. ACKNOWLEDGEMENT

This study is based on the publications available in the libraries of National Oil Corporation and Agip Company of Tripoli, G.S.P.L.A.J. The authoress would like to express her thanks to Management of these libraries for use of materials and photocopying services. Also thanks are due to Prof.Mazur of Petroleum Institute, Tripoli for conversations.

5. REFERENCES

[1] - Wymer, N., Behind the scenes on an Oilfield, Phoenix House, London, 1964.
[2] - Energy Statistics, Vol.10 No.4, Fourth Quarter 1987.
[3] - World Oil, January 1987, 63-64, 86-87, January 1988, 85, March 1988, 47, June 1988, 57, 144.
[4] - "The interactive exploration systems exist today", World Oil, October 1987.
[5] - Underwater System Design, May 1987, 4-5, 24,26.
[6] - "Processing leads the way in seismic breakthroughs", Noroil, March 1988.
[7] - Saunders, D.F., and Thompson, C.K., "Integrated exploration improves wildcat success", World Oil, November 1987.
[8] - Brandsoeter, H., "Computers to play major role in exploration", Noroil, March 1988.
[9] - Nakamura H., and et.al., "Large-offset seismic surveying", Geophysics, December 1987.
[10]- Rodsten, S., and Trostheim, J.,"Asea Master goes offshore", Asea Journal 5-87.
[11]- Mackenzi, A.S., and Quigley, T.M., "Principles of Geochemical Prospect Appraisal", AAPG Bulletin,April 1988.
[12]- Brown, A.R., "Interpratation of 3-D seismic data", AAPG Bulletin, April 1988.
[13]- Bansal, P.P., and et al., "A Three-Phase Simulator with Strongly Oriented Field Features", SPE Middle East Technical Conference, March 25-29, 1979.
[14]- Haut, R.C., "New Developments in Completions Technology", Damascus, Syria, October 6-10, 1985.
[15]- Nierode, D.E., "Comparison of Hydraulic Fracture Design Methods to Observed Field Results", The SPE - AIME 58th Annual Fall Technical Conference and Exhibition, San Francisco, U.S.A., October 5-8, 1983.
[16]- Offshore Engineer, March 1988, 48.
[17]- Swain, F.A., "Development and Facilieties of the well information system", Proceedings of the Symposium on Petroleum Information Management Systems, Dhabi, U.A.E., September 26-29, 1983.
[18]- Howes, J., "The drilling programme", The Oilman, April 1988.
[19]- Warrier, R.C., "Information requirements of petroleum exploration and production and need for a data base", Proceedings of the Symposium on Petroleum Information Management Systems, Dhabi, U.A.E., September, 26-29,1983.
[20]- Graser, J.A., "Development of a Subsea Wireline Winch System", SPE Production Engineering, August 1987.
[21]- Chung, J.S., "Offshore and Arctic Frontiers - Structures, Ocean Mining", Mechanical Engineering, May 1985.

[22]- Bos, A., and du Chatinier, J.G., "Simulation of Gas, Liquid Flow in Slug Catchers", SPE Production Engineering, August 1987.

[23]- Pipeline, March 1987, 24, 26, 38-39.

[24]- Hydrocarbon Processing, February 1986, January 1987,62-63 March 1987, 110, 112-114, 117-118, 126, January 1988, 86.

[25]- Smith, R.C., and et.al.,"Postanalysis of Abnormal Cementing Simulator", SPE Production Engineering, August 1987.

[26]- Wittman, M., "New Developments in Production Logging", Proceedings of the Seminar on New Techniques of Petroleum Production, Damascus, Syria, October 6-10,1985.

[27]- "Sharpening the technological edge in oil", Marathon World, 1987.

[28]- Ocean Industry, June 1988, 16.

[29]- Drzewiecki, T.M., "A control technology for the micro-processor age", Mechanical Engineering, March 1985.

[30]- Asquith, G.B., Log analysis by microcomputer, 1980, PennWell Books, Tulsa, Oklahoma.

[31]- Howes, J., "Wrestling with muds", The Oilman, April 1988.

[32]- Simons, G.L., Expert systems and micros, NCC 1985.

[33]- Miller, B.M.,"Building an Expert System Helps Classify Sedimentary Basins and Assess Petroleum Resources," Geobyte, AAPG Bulletin, 1, No.2, Spring 1986.

[34]- Miller, B.M.,"Future Applications of Expert Systems for the Evaluation of Energy Resources", Journal of Petroleum Technology, March 1988.

[35]- Baker, J.D., "DIPMETER ADVISOR: An Expert Log Analysis System at Schlumberger", in Winston, P.H. and Prendergast, K.A., eds., The AI Business: Commercial Uses of Artificial Intelligence, The MIT Press, Cambridge, MA, 1984.

SOME PROPERTIES OF VACUUM DEPOSITED GaAs THIN FILMS

M. N. ISLAM
Solid State Research Laboratory
Dept.of Applied Physics & Electronics
University of Rajshshi 6205
Bangladesh

ABSTRACT

Thin film of GaAs obtained by vacuum sublimation onto glass substrate at room temperature from a thermally heated quartz crusible at about 650°C at a pressure of $2x10^{-6}$ torr. Electrical resistivity, Hall mobility carrier concentration and activation energy of as deposited films of thickness between 0.12μm to 0.64μm were measured on a Vander Pauw specimen using dc method. The resistivity varies from $3.0x10^{5}$ to 2.0x 10^{4} ohm-cm and mobility from 0.63 to 1.52 cm^2/v-sec as an increasing function of film thickness while the activation energy decreased from 0.12ev to 0.13ev with increase of thickness. Temperature coefficient of resistivity (TCR) was negetive for all the samples atudied. Thermo electric power as a function of temperature were measured and the samples were found to be n-type.

The electrical resistivity of undoped flash-evaporated GaAs films ranged from $4.2x10^{8}$ ohm-cm at a thickness of 500A° to $1.3x10^{7}$ ohm-cm at 3000A°. Samples doped with tellurium(Te) between 0.2 to 1.0 wt% of 0.3μm thickness had resistivity between 0.16 to 4.95 ohm-cm. Thermoelectric power measurements of undoped samples suggested that the samples were p-type, whereas the tellurium doped samples were found to be n-type. The optical band gap for samples deposited at room temperature was 0.90ev and for samples deposited at 250°C was 1.3ev.

1.0 INTRODUCTION

The semiconductor like GaAs has been intensively investigated in recent years. It is a potential competitor of silicon because of diverse applications. GaAs has higher absorptance and the band gap is about 1.35ev close to optimum for the solar power conversion. In thin film gallium arsenide solar cells, the active semiconducting layers are polycrystalline. Gallium arsenide films are produced by sublimation[1,2], flash evaporation[3,4,5], sputtering[10] ,molecular beam deposition[11] ,three temperature zone[12,13], plasma deposition [11] , etc. They show widely different properties as compared to those obtained by flash evaporation. A systematic study of electrical, thermoelectric and optical properties of the two distinct types (sublimed and flash evaporated) of GaAs thin films deposited on glass substrates is presented in this paper.

2.0 EXPERIMENTAL

2.1. Preparation of the samples both sublimed and flash evaporated GaAs films were prepared in a Coating Unit E306. The substrates were cleaned and cooked in vacuum at 250°C for 30 minutes and cooled down/raised slowly to the required temperature. For sublimation and flash evaporation the substrates were placed at a distance of 8cm and 10cm from the crucible/tantalum cup respectively. The optimum source temperature for the sublimed and flash evaporated films were 650°C and 1400°C respectively at a pressure of 2×10^{-6}torr. For the doped films the charge used was a mixture of GaAs powder and a dopant powder.

2.2. Electrical resistivity were measured using Vander Pauw methods. Contacts were made using evaporated indium. A Keithly 610 C Solid State electrometer and HP 412ADC multimeter with high input impedance were used for resistivity measurments. A thermocouple was used to measure the substrate temperature. The conductivity(σ) and thermoelectric power(S) were measured with respect to gold between 303°K to 400°K. The thickness was measured using Tolansky's interferometric method. Optical absorptance measurements were made using a Shimdzu UV-180 double beam spectrophotometer in the 0.50μm to 0.90μm. The absorption spectra were not corrected for reflection losses. High absorption levels being used, and so the reflection correction was not so important. From the absorption data the absorption coefficient was calculated and the optical band gaps were determined graphically.

3.0 RESULTS AND DISCUSSION

3.1 Sublimed Films:

The room temperature resistivities of the sublimed GaAs films were found to vary from $3x10^5$ to $2x10^4$ ohm-cm for the film thickness from 0.1 to 0.60μm. The results are close to those of Kenji Kumabe et al.[10] on sputtered GaAs films. Figure 1 shows the variation of the resistivity with substrate temperature. The lowest value of resistivity of about $3x10^3$ ohm-cm were obtainable only in a narrow temperature range (240°-260°C) of deposition. The conductivities were n-type. Hall mobility and carrier concentration for a typical film thickness were 1.52cm^2/v-sec and $2.1x10^{15}$cm^{-3} respectively. The variation of resistivity may be explained as to reduction in imperfection and then due to weak texture or onset of crystallization. The lowest resistivity of $3x10^3$ ohm-cm for a substrate temperature of about 250°C was probably the result of strong texture i,e, amorphous phase transforming into crystalline phase. With further increase of substrate temperature the remarkable rise in resistivity may due to the generation of grain boundaries. A visual test shows that the samples became more transparent, when the substrate temperature is higher than 200°C. Thickness dependance of TCR and sheet resistance are shown in Fig. 2 and Fig. 3 respectively. The TCR was negative for all the samples. It is seen from conductivity versus temperature study of GaAs films of different thickness that TCR and sheet resistance showed surface effects below 0.25μm. The variation of thermoelectric power as a function of film thickness is shown in Fig. 4. The thermoelectric power decreased with increasing thickness showing the homogeneity of the sublimed films. There was sharp change of thermoelectric power in thickness range 0.10-0.25μm, and weaker variation in the range 0.25μm-0.30μm. The constancy of thermoelectric power above 0.30μm thick film may be due to constancy of crystallite sizes. The sharp variation of thermoelectric power may be due to surface effects.

The behaviour of absorption coefficient of the samples deposited at 30°C and 250°C as a function of photon energy are shown in Fig. 5. The spectra at 30°C and 200°C indicating the transition and the calculated optical band gaps were 0.93ev and 1.10ev respectively, while that of films deposited at 250°C was 1.32ev. The results are in good agreement with other reported values [11].

3.2 Flash-Evaporayed Films:

The GaAs films prepared by the flash evaporation method are very stable. The films deposited at room temperature were dark-grey in colour. The room temperature resistivity varied from $4.2x10^8$ ohm-cm at a thickness of 500Å to $13x10^7$ ohm-cm at 3000Å. The results are in close agreement with Segui et al.[14] . The thermoelectric power measurements of the flash evaporated films were found to be p-type. Figure 6 shows the variation of resistivity with film thickness. The

rapid change in resistivity between 500-1500A° may be due to the surface effects and the weaker variation upto 2000A may be due to increase in grain size.

Figure 7 shows the variation of conductivity σ, mobility μ_H and carrier concentration n of Te doped films of about 0.25μm thick, as a function of doping concentration. The conductivity of Te doped films varied from 6.41ohm^{-1}-cm^{-1} to about 0.20 ohm^{-1}-cm^{-1}, at room temperature within the doping concentration range 0.2 to 1.0 wt%. Measured carrier concentration ranged from approximately 3×10^{17} to 6.1×10^{18}cm^{-3}. N-type Hall mobility varies from 4.2cm^2/v-sec at a Te concentration of 0.2 wt% to a maximum of about 8.0cm^2/v-sec at 0.65 wt% and thendecreased to about 4.5cm^2/v-sec at 1.0 wt%. The values are comparable to tin-doped films . Figure 8 represents the mobility and thermoelectric power of Te doped GaAs films with various doping as a function of carrier concentration n. The slow increase of μ_H with increase of Te doping upto 0.65 wt% may be mainly due to lattice scattering and ionized impurity scattering may be responsible for decrease in mobility. Thermoelectric power s of the samples of various Te concentrations between the temperature range 30°-127°C decreases linearly with increasing carrier concentration n.

The absorption coefficient vs photon energy larger than 1.3ev is shown in Fig. 9 in undoped film of 0.25μm thick. The value of the optical band gap of the samples deposited at room temperature and at 250°C were 0.90 and 1.34ev respectively. By extrapolating the linear portion of the plots the room temperature result is in agreement with amorphous GaAs films by the flash evaporation method .

The variation of conductivity with temperature for the samples deposited at room temperature and those at 150°C is shown in Fig. 10. The calculated value of activation energy deposited at room temperature was 0.215ev and those deposited at 250°C was 0.60ev. The activation energy deposited at room temperature agrees well with those of amorphous GaAs films obtained by molecular beam deposition .

4.0 CONCLUSION

A comparison of the electrical and optical properties of the sublimed and flash evaporated GaAs films showed that they are suitable for solar cell application.

5.0 REFERENCES

1. Hudock, P. J., Electrochem. Soc. 114(1967), 64C, Abstract No. 101,
2. Yan, G. et al., 14 (1971),1003.
3. Richards, J. L. et al. J. Appl. Phys. 34(1963), 3418.
4. Muller, E. K., J. Appl. Phys. 35(1964), 580.
5. Light, T. B. et al., J. Electrochem. Soc.115(1968),857.
6. Pankey, T. et al., J.Appl. Phys. 37(1966), 1507.
7. Furukhi, M. R. et al. J.Appl. Phys. 40(1969),3561.
8. Barthwal, S. K. et al. Phys.Stat.Sol,(a)36(1976),345.
9. Gheorghiu, A. et al. Thin sSolid Films,120(1984),191.
10. Kumabe, K. et al. Japan J. Appl.Phys. 18 (1979),1789.
11. Matsumoto,N. et al. Japan J.appl.Phys. 19(1980),1583.
12. Davey, J.E. et al. J. appl. Phys. 35 (1964), 2003.
13. Takashi, K. Jac. Sci. Techno. 9 (1971), 502.
14. Segui, Y. et al. Thin Solid Films, 92 (1982), 303.

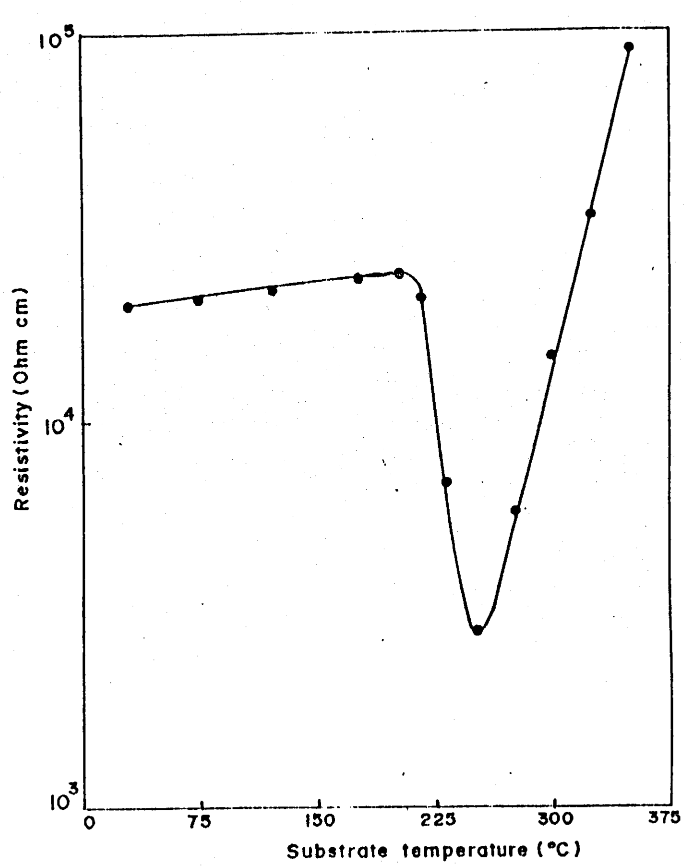


Fig. 1 . The resistivity of sublimed GaAs films 0.60 µm thick, as a function of substrate temperature.

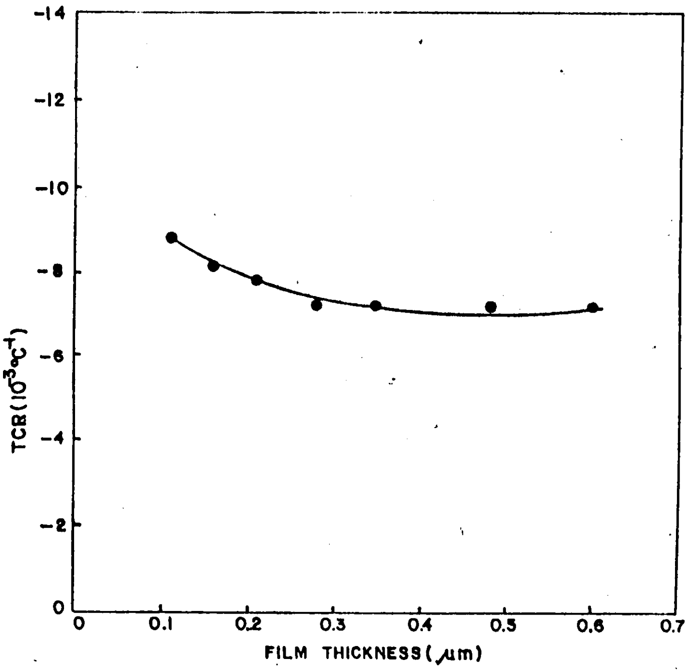


Fig. 2. Thickness dependence of TCR of sublimed GaAs films deposited at room temperature.

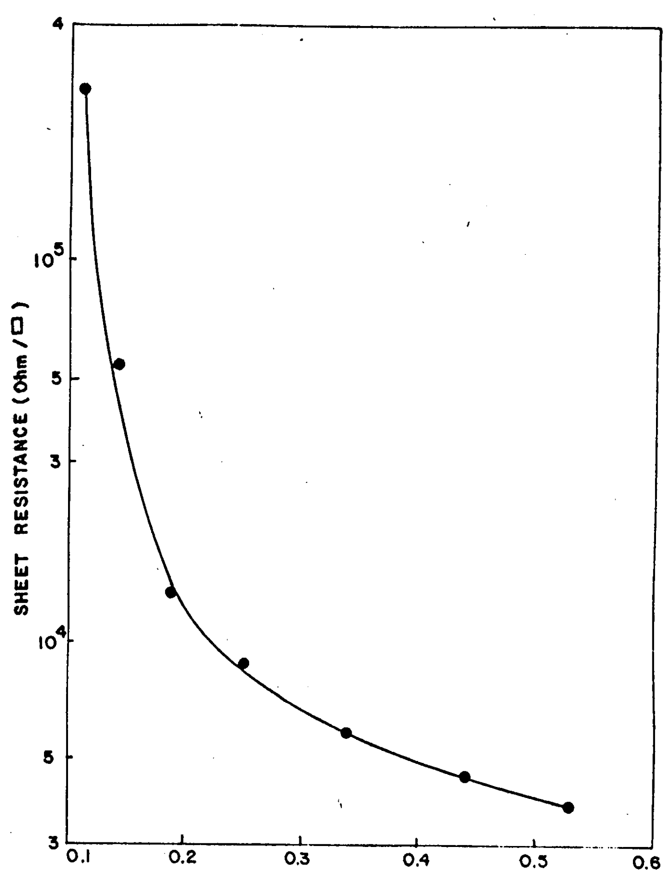


Fig. 3. Sheet resistance as a function of film thickness for sublimed GuAs films deposited at room temperature.

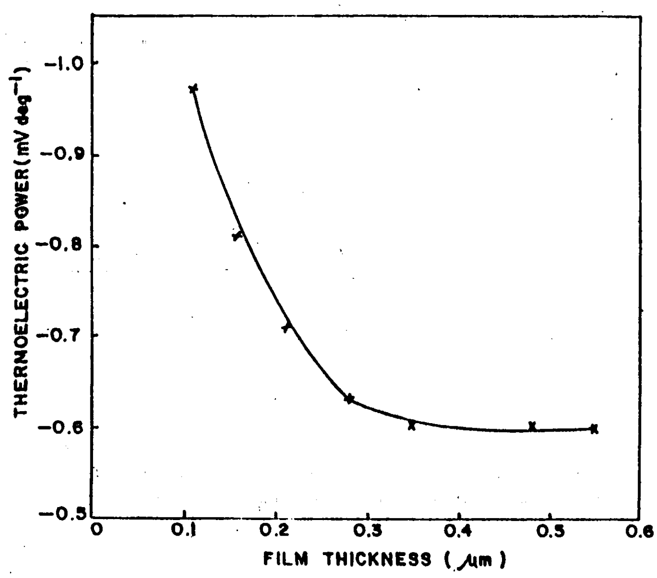


Fig. 4: The variation of thermoelectric power as a function of film thickness of GaAs films deposited at 250°C.

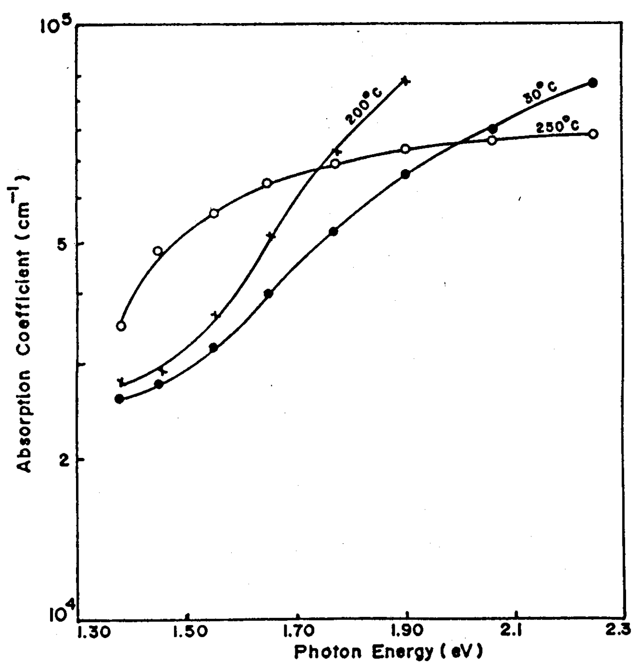


Fig. 5. The changes in the optical absorption as a function of photon energy for GaAs films deposited at 30° C, 200° C and 250°C .

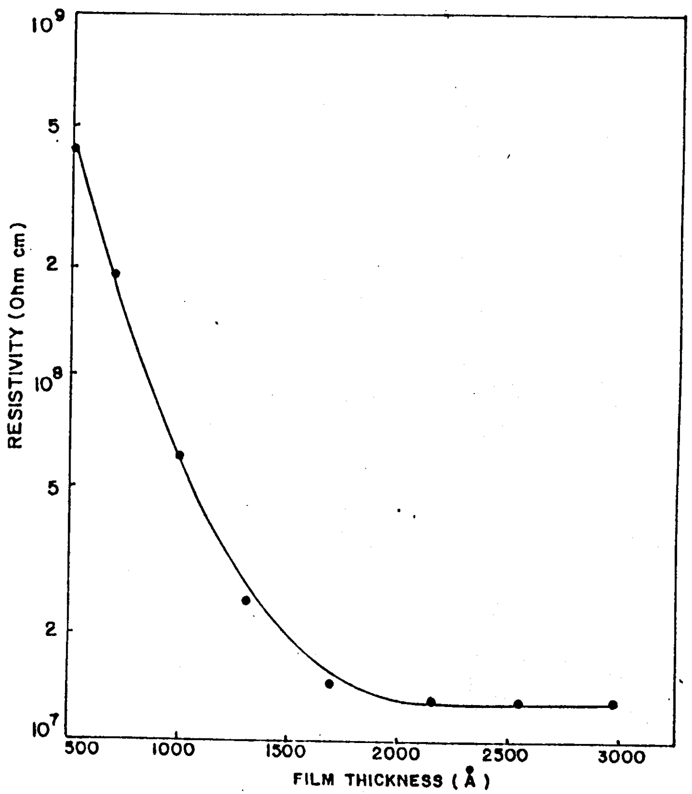


Fig.6. The changes in resistivity of flash evaporated GaAs films deposited at room temperature with film thickness.

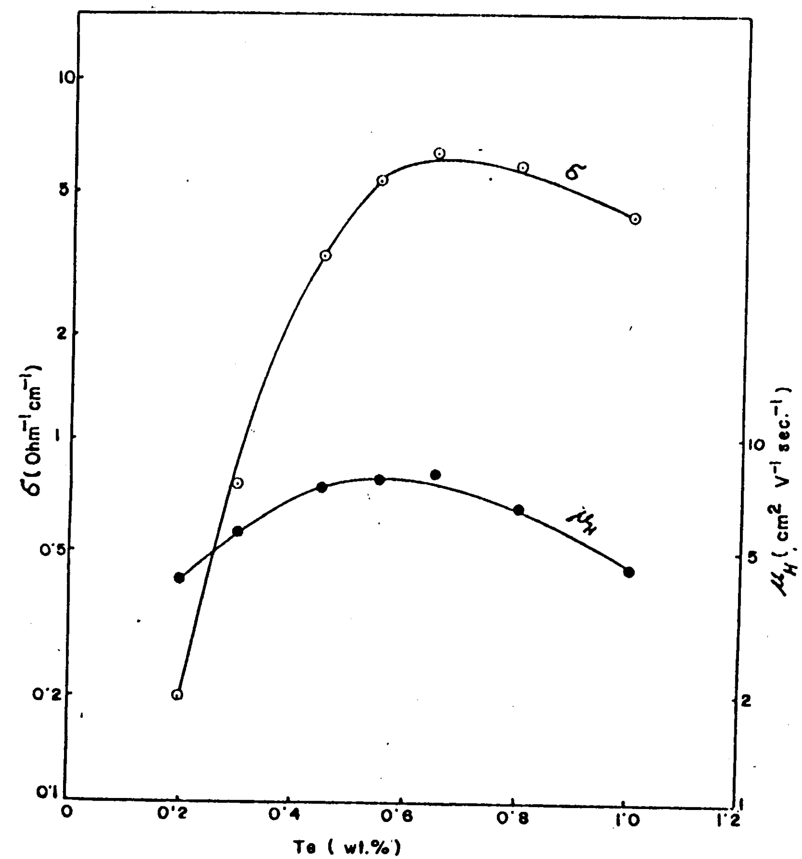


Fig.7. The curves of σ and μ_H versus Te-doping concentration of GaAs films deposited at temperature 350°C.

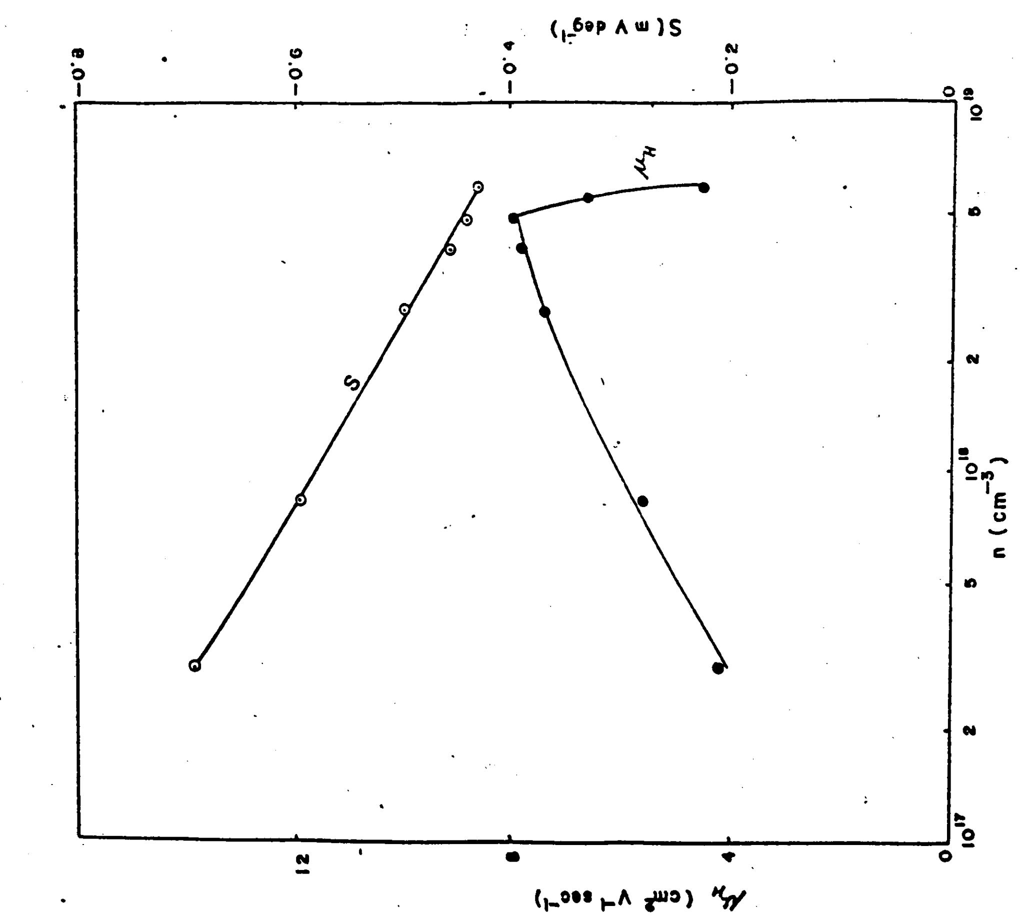


Fig.8. The variation of μ_H and S as a function of carrier concentration of Te-doped GaAs films deposited at temperature 350°C.

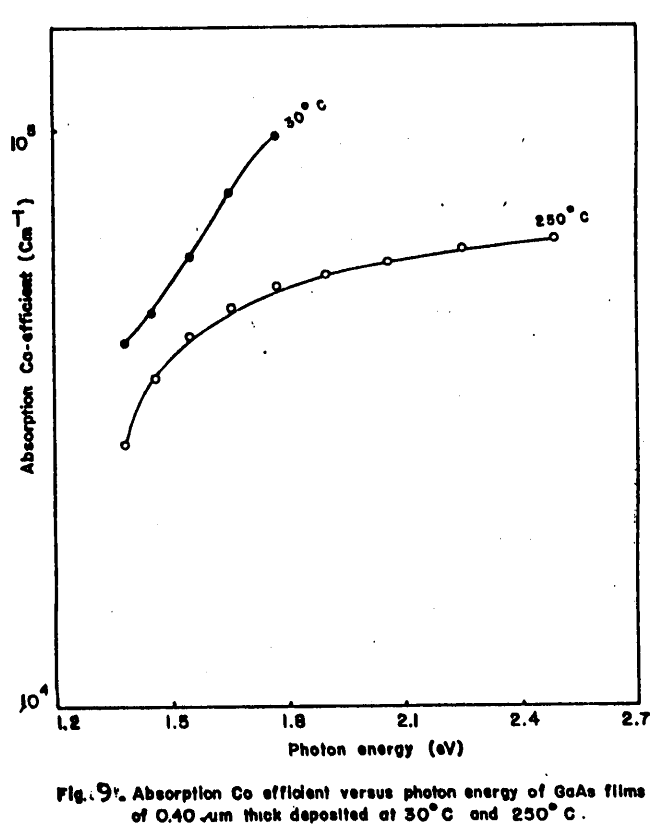


Fig. 9. Absorption Co efficient versus photon energy of GaAs films of 0.40 μm thick deposited at 30°C and 250° C.

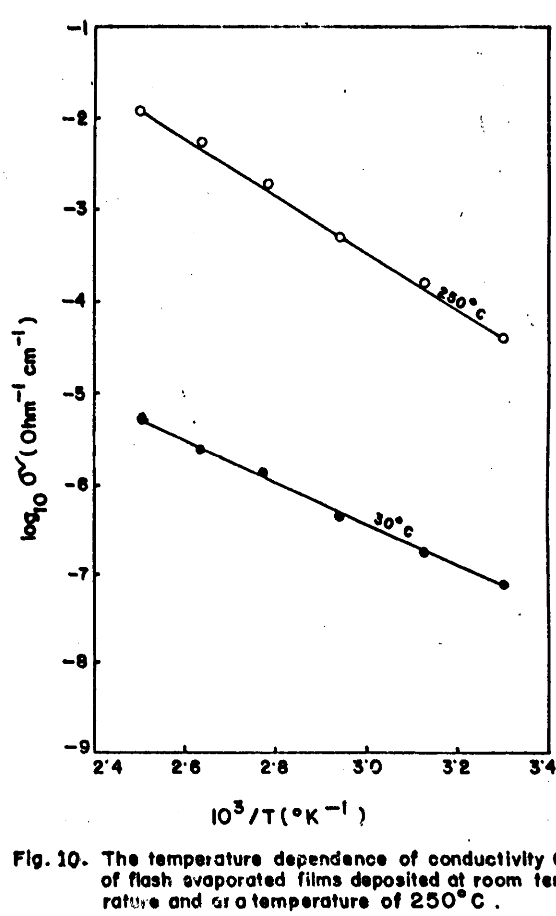


Fig. 10. The temperature dependence of conductivity σ of flash evaporated films deposited at room temperature and at a temperature of 250° C.

SECTION IV

ECONOMY AND CONSERVATION

THE USE OF ECONOMICAL ANALYSIS IN PIPELINE DESIGN

Abdul-Karim Busedra

Mechanical Engineering Dept.
University of Garyounis

ABSTRACT

Economic pipe size has been determined at minimum annual total cost. Data were gathered on the basis of a known oil pipeline material. It was chosen to be API 5 LX - Grade X 52 according to the existing oil pipline from Sarir field to Tobruk.

A computer program has been modified for an iterative solution of the friction factor as a function of Reynolds number and pipe roughness. However, the computed friction factor values at several pipe sizes have been used to obtain a relation between the friction losses and power output in terms of pumping equipment cost.

A relation between the pipline cost and the pumping equipment cost has been developed through the available prices of different pipe diameters. Thereafter, the estimated annual fixed cost was applied to the pipline for thirty years total field life and interest rate of 10%.

The energy consumed by the pumps has been ascertained to calculate the annual running power cost. This amount was added to the annual fixed cost to evaluate the annual total cost. The best pipe size for installation was shown to be at the minimum annual total cost.

1. INTRODUCTION

The problem of determining the economic oil pipeline from Sarir Field to Tobruk is analyzed. There are comparatively many studies in the field of optimum pipe size evaluation. Theoretical consideration of pipe cost and pumping cost in which the flow is laminar and turbulent was presented in Re [4] . This study is valid only for incompressible fluid flow through a pipe of constant diameter.

The optimum pipe diameter has the least annual total cost as specified by Re [6] . That is, if the power cost increases, a large pipe diameter would be more economical and if pipe prices increases, a smaller pipe would be better. Analytical studies for more than one scheme of pimping system were discussed in Re [3] considering more than one class or type of pump, piping arrangement and driver.

The present study involves the case of a known oil pipe line material. GradeX has been chosen due to its high tensile strength and welding quality, Re [5] .
In adition, this selection was based on the existing oil pipline which is 513.7 Km long from Sarir Field to Tobruk.

Since the pipeline has a uniform pipe diameter, the power output can be written in terms of the energy equation;

$$P= \gamma QH \qquad (1)$$

Where,

$$H= \Delta Z + f \frac{L}{D^5}\ 8\ \frac{Q^2}{\pi^2 g}$$

A comparison of more than one scheme of pumping system has been proposed to secure the lowest annual total cost for handling the required capacity of 750,000 barrels of oil per day.

2. PUMPING EQUIPMENT COST

2.1 The Friction Factor

A computer program, Re [2] , has been modified for an terative solution of the friction factor as a function Reynolds number and pipe roughness. Values of the friction factor change very slowly with large change in Reynolds number for several pipe diameters as indicated in Table 1.

TABLE 1 VALUES OF THE FRICTION FACTOR AS A FUNCTION OF REYNOLDS NUMBER AND PIPE ROUGHNESS

Flow Data

ρ = 856 Kg/m^3
ν = 0.00001 m^2/s
Q = 1.38 m^3/s

D(CM)	ϵ/D	Re	f
40	.000115	439268	.00366
45	.000120	390460	.00376
50	.000092	351414	.00376
55	.000084	319467	.00376
60	.000077	292845	.00386
65	.000071	270319	.00386
70	.000066	251010	.00386
75	.000061	234276	.00396

80	.000058	219634	.00396
85	.000054	206714	.00396
90	.000051	195230	.00405
95	.000048	184955	.00405
100	.000046	175707	.00405
105	.000044	167340	.00415
110	.000042	159734	.00415
115	.000040	152789	.00415

Cost data of the purchase of motor driven centerifugal pumps were collected from Arabian Gulf Oil Company. Figure 1 depicts the cost of pumping equipment versus pump horsepower.

3. OIL PIPELINE COST

Prices of different pipe sizes have been supplied by Pipe Manufacturer Factory, Benghazi. Therefore, a plot of the logarithm of the pipe diameter versus the logarithm of the purchase cost per meter of pipe is represented in Fig. 2.

4. ESTIMATED ANNUAL FIXED COST

The Field production decline is anticipated to be at annual rate of 10% for about thirty years total Field life. The estimated annual fixed cost Re [7] is evaluated by summing the annual pumping equipment cost and the annual oil pipeline cost.

$$FIX = [\, PE + PL \,] \left[\frac{i(1+i)^{n}}{(1+i)^{n}-1} \right] \qquad (2)$$

5. ANNUAL RUNNING POWER COST

It depends on the energy consumed by the pump and its horsepower. The price of 1 Kw-hr is equal to 0.02 LD as quoted by Electricity Company, Benghazi. Thereafter, an equation, Re [3], for the annual running Power cost is modified;

$$RUN = 24 * 365 * 0.0531 \, [\, P \,]^{.889} \qquad (3)$$

6. ANNUAL TOTAL COST

It can be obtained by adding Eqs (2) and (3). The best size of the oil pipeline for installation is shown to be 85Cm at minimum annual total cost of 5547395 LD (see Table 2 and Fig.3)

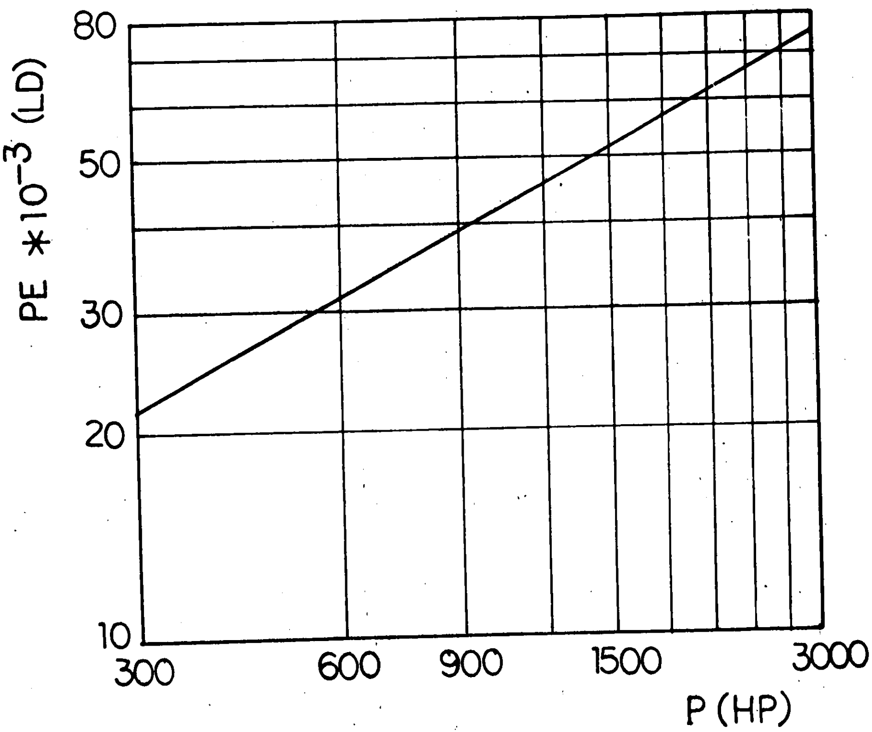


FIG. 1 PUMPING EQUIPMENT COST

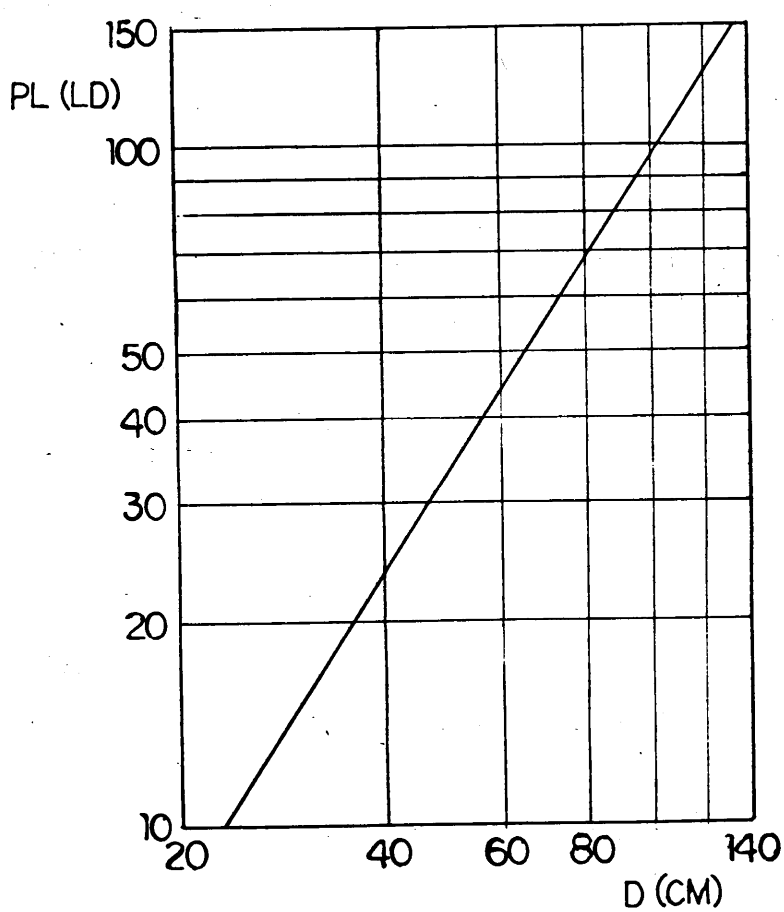


FIG. 2 PIPELINE COST PER METER

TABLE 2 DETERMINATION OF ECONOMIC PIPE DIAMETER

D (cm)	FIX (LD)	RUN (LD)	TOTAL (LD)
40	1338568	32920324	34258892
45	1550065	20087076	21637141
50	1786279	12700274	14486553
55	2043778	8436329	10480107
60	2320015	5975668	8295684
65	2611770	4302760	6914530
70	2918348	3208322	6126671
75	3239015	2517264	5756279
80	3572370	1996609	5568979
85	3918139	1629255	5547395
90	4275965	1385047	5661012
95	4645308	1214444	5859752
100	5025313	1041052	6066366
105	5416401	940572	6356973
110	5817877	854831	6672708
115	6229585	788894	7018480

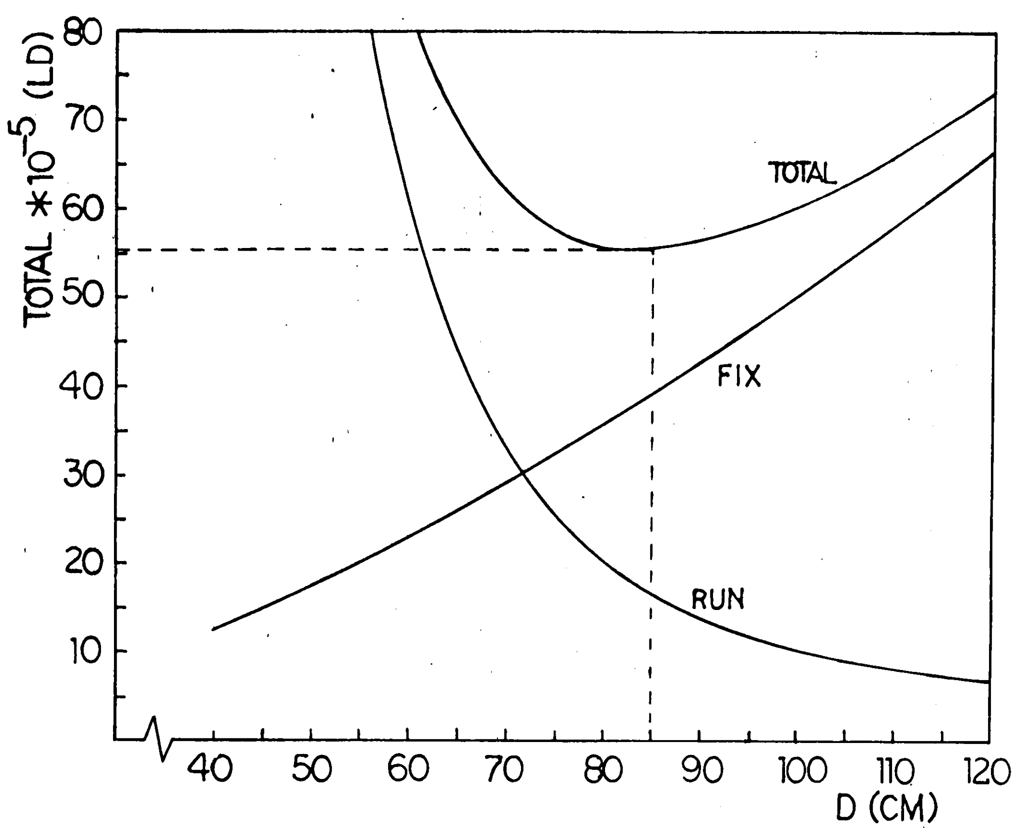


FIG 3 ECONOMIC PIPE DIAMETER

7. PUMPING SYSTEM

Figure 4 shows the system head curve for the oil pipeline. Figure 5 represents the corresponding pressure heads(P/γ)of 735m for Main Oil pump station (MOPS) and 572 m for Booster Stations (BS)at maximum capcity. At minimum capacity the pressure heads are 344 m for MOPS and 200 m for BS.

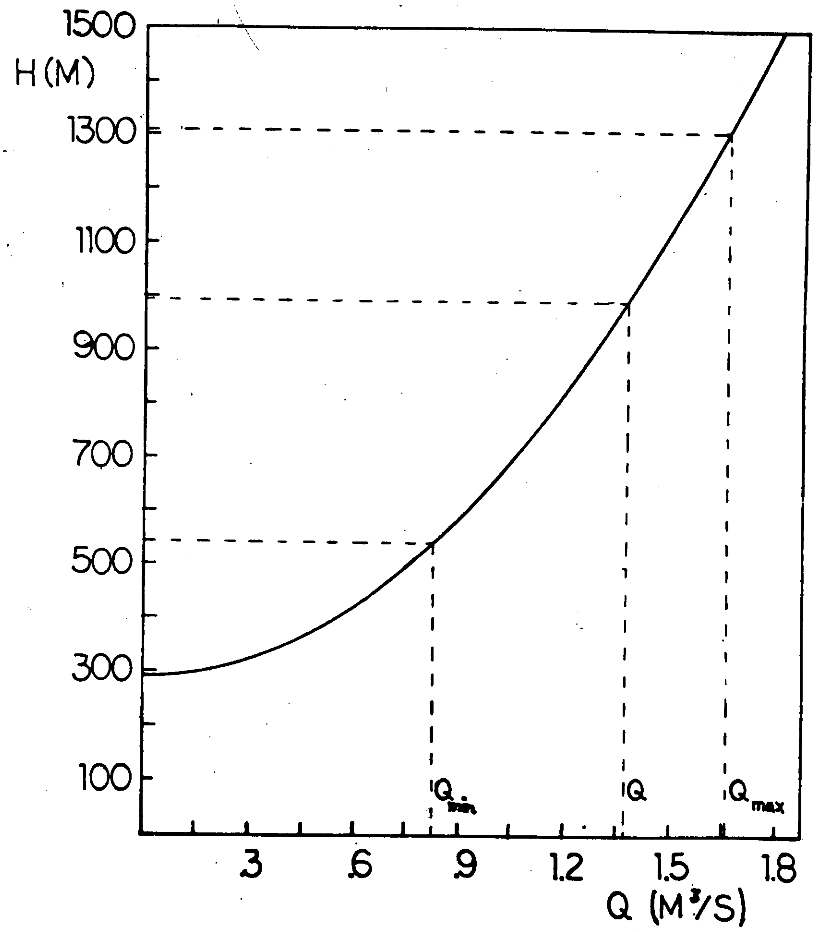


FIG.4 SYSTEM HEAD CURVE FOR THE OIL PIPELINE

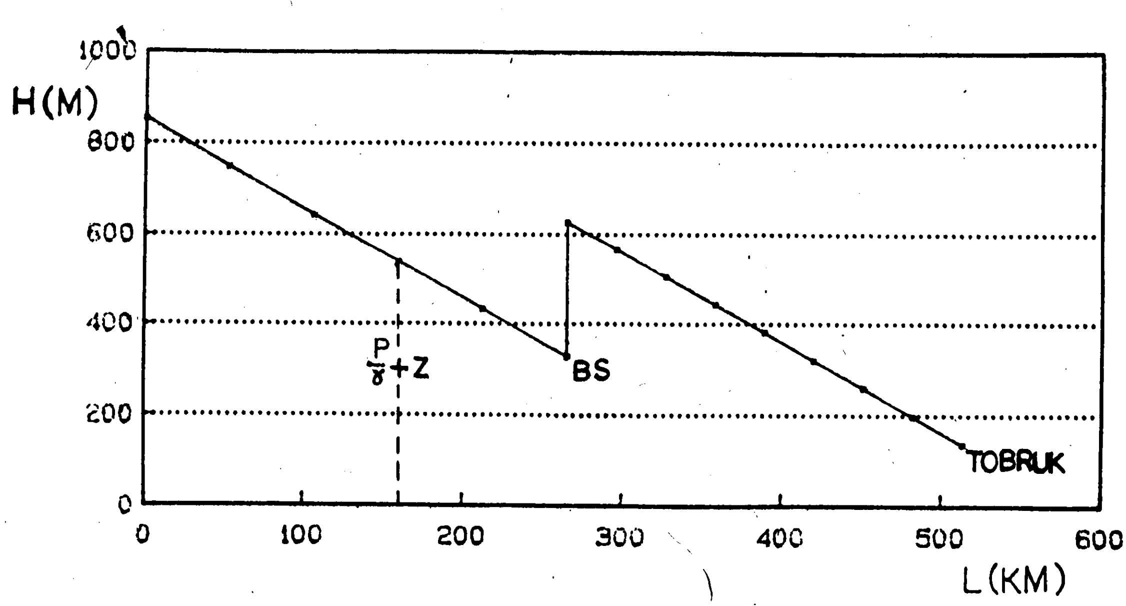


FIG.5 PRESSURE HEAD PROFILE

Two schemes have been proposed for handling the required capacity of 1.38 m^3/s. The mode of pumping is divided into two categories. During day time of sixteen hours pumps run to supply maximum capacity of 1.66 m^3/s. At night only half of this capacity should be delivered (0.83 m^3/s).

7.1 Scheme 1

Two pumping units run in parallel to discharge maximum capacity and one unit runs to supply minimum capacity. Each pumping unit, for MOPS, consists of four centrifugal pumps connected in series along with a stand-by pump. For BS, each pumping unit is to be capable of existing three centrifugal pumps connected in series along with a stand-by pump. The two units for each station are identical.

7.2 Scheme 2

Two different pumping units , one unit runs to deliver maximum capacity and the other unit runs to supply minimum capacity. The unit for MOPS consists of five centrifugal pumps connected in series along with two stand-by pumps. For BS, the unit consists of four centrifugal pumps connected in series along with two stand-by pumps. Both units are for supplying maximum capacity. To satisfy the needs for minimum capacity, the unit for MOPS consists of two centrifugal pumps connected in series along with a stand-by pump. And the unit for BS consists of one centrifugal pump along with a stand-by pump.

8. ECONOMIC ANALYSIS IN PUMPING SYSTEM

Number of hours per week for maximum and minimum capacities are 112 and 56 hrs/week respectively.

8.1 Annual Cost of Consumed Power

$$\text{Power consumed per week} = \frac{P/\eta}{\eta_{em}} * \text{No of hrs/week} \qquad (4)$$

Where η_{em} equals to 97% for the selected motor driven centrifugal pumps and P in Kilowatt.

$$Pc = \text{Power consumed per year} * \text{Price of 1 kw-hr} \qquad (5)$$

8.2 Cost of Units

The power output for one pump is calculated from Eq (1). Accordingly , the cost of the pump can be obtained from Fig (1).

$$\text{Cost of units} = PE * \text{No. of pumps} \qquad (6)$$

8.3 Estimated Annual Fixed Cost

$$FIX = [\text{ cost of units }]\left[\frac{i(1+i)^n}{(1+i)^n-1}\right] \quad (7)$$

8.4 Annual Total Cost

It is evaluated by adding Eqs (5) and (7). Results obtainable for the two schemes are summarized in Table 3 & 4

TABLE 3 SUMMARY OF THE RESULTS FOR SCHEME 1

SCHEME 1	MOPS		BS	
	DAY	NIGHT	DAY	NIGHT
Head	735	367.5	572	191
Capacity	1.66	0.83	1.66	0.83
Overall effeciency	0.88	0.87	0.88	0.88
Power output in Kw, Eq(1)	10246	2561	7973.5	1331
No of running pumps	8	2	6	1
Power consumed per week, Eq(4)	1344324	169972	1046195	87335
Total power consumed per week	1514296		1133530	
Total power consumed per year	78743390		58943560	
Annual cost of power, Eq(5)	1574868		1178871	
Cost of units, Eq(6)	560942		457789	
Estimated annual fixed cost, Eq(7)	59516		48571	
Annual total cost	1634384		1227442	
Annual total cost for MOPS and BS	2861826			

TABLE 4 SUMMARY OF THE RESULTS FOR SCHEME 2

SCHEME 2	MOPS		BS	
	DAY	NIGHT	DAY	NIGHT
Head	735	344	572	200
Capacity	1.66	0.83	1.66	0.83
Overall effeciency	0.88	0.87	0.87	0.87
Power output in Kw, Eq(1)	10246	2398	7973.5	1394
No of running pumps	5	2	4	1
Power consumed per week, Eq(4)	1344324	159128	1058220	92504
Total power consumed per week	1503452		1150724	
Total power consumed per year	78179497		59837649	
Annual cost of power, Eq(5)	1563590		1196753	
Cost of units, Eq(6)	506105	138628	364834	100253
Total cost of units	644733		465087	
Estimated annual fixed cost, Eq(7)	68406		49346	
Annual total cost	1631996		1246099	
Annual total cost for MOPS and BS	2878095			

9. RESULTS AND DISCUSSION

9.1 Economic Pipe Size

The results obtained in Table 2 show the variation of the annual total cost with pipe diameter. As the pipe size increases, the estimated annual fixed cost increases with decreasing in the annual running power cost.

The results are also shown in Fig. 3 for different pipe diameters. The best oil pipeline size for installation is shown to be 85cm at minimum annual total cost of 5547396 LD. The results of the present study for pipeline diameter are in good agreement with the existing pipeline size(86.36cm).

9.2 Economic Pumping System

scheme 1 is capable to provide the required capacity of 750,000 barrels of oil per day at the lowest annual total cost of 2861826 LD. The annual total cost for scheme 2 is considerably more than scheme 1 (see Table 3 and 4).

The results of the present study for scheme 1 coincide, in pumping arrangement,with those existed at Sarir field. The existing pumps at BS, Re[1],are turbine driven centrifugal pumps. While the results obtainable for BS have been computed for motor driven centrifugal pumps.

10. REFERENCES

[1] - Arabian Gulf Oil Company , Sarir Field Operation and Maintenance , Vol.I , 1965.

[2] - Douglas, J.F, Gasiorek, J.M. and Swaffield, J.A., Fluid Mechanics , Pitman , 1985.

[3] - Hicks, T.G. and Edwards, T.W., Pump Application Engineeing, McGraw Hill, 1971.

[4] - Max, S.P. and Klaus, D.T., Plant Design and Economics for Chemical Engineers, 2nd ed, McGraw Hill, 1968.

[5] - Petroleum Extension Services, Oil Pipeline Construction and Maintenance, The University of Texas, 1973.

[6] - Rodger,W., Pump Selection, Ann Arbor Science Publishers, Inc., 1972.

[7] - Thusen, H.G., Febrycky,W.J. and Thusen,G.J., Engineering Economy, Prentice Hall, 1971.

NOMENCLATURE

D = diameter of the pipeline
g = acceleration due to gravity
i = interest rate
n = number of years
Pc= annual cost of consumed power
Re= Reynolds number
FIX=estimated annual fixed cost
PE= pumping equipment cost
RUN=annual running power cost
ρ = density
γ = specific weight
η_{em} = motor efficiency
f = friction factor
H = discharge pressure head
L = length of the pipeline
P = power output
Q = rate of flow
ΔZ= elevation differance
LD= libyan dinar
PL= oil pipeline cost
TOTAL=annual total cost
ν = kinematic viscosity
η = overall efficiency
ϵ = roughness of the pipeline

ENERGY CONSERVATION IN A CATALYTIC REFORMING PLANT

Dr. A.A. Ballut

Department of Chemical Engineering
Al-Fateh University
P O Box 13317, Tripoli, Libya.

1. INTRODUCTION

Catalytic reforming of naphtha to produce high quality gasoline is an important petroleum refining process. It is essentially a high temperature process involving extensive use of direct heat and accounts for as much as 10% of the energy consumed in a typical refinery. Most of this energy is required to preheat reforming reactor feeds to the desired reaction temperature in order to maintain reasonably high reaction rates. As with other refining units such as crude topping units (1,2), significant energy conservation opportunities exist in a catalytic reforming unit.

In this paper an existing catalytic reforming unit (Azzawia Refinery) is examined to determine the efficiency of energy utilization and prospects for its improvement. Particular attention is directed towards potential energy conservation in the reforming reaction section using both the first and second law of thermodynamics analysis.

2. PROCESS DESCRIPTION

The semi-regenertive UOP platforming process is the process used in the Azzawia Refinery. A simplified flow diagram of this process is given in Fig. 1. The process employs a bimetallic, bifunctional catalyst contained as fixed bed in three reactors in series. The reactors operate in the range of 450-540^{o}C and 200-500 psig. The principal reactions involved are dehydrogenation of naphthenes to aromatics, dehydrocyclization of paraffins, isomerization of paraffins and naphthenes, and hydrocracking of high molecular paraffins and napthenes. The reforming reactions are largely endothermic calling for substantial preheating of the initial charge and subsequent reheating between reactors. Effluent from the third reactor is cooled and then partially condensed and the product mixture is separated into liquid and gas streams. The separated gas being rich in hydrogen is recycled to the reactors and a net hydrogen byproduct stream is withdrawn for use in naphtha and kerosene hydrodesulfurization reactors. The liquid product from the separator is sent to the stabilizer to produce stabilized reformate. The lighter ends are removed from the top of the stabilizer as a byproduct.

3. FEEDSTOCK AND STUDY BASIS

Normally, the catalytic reforming unit processes heavy naphtha produced from refining either a 100% Essider Crude or a 50-50 mix of Essider and Hammada crudes. The energy utilization analysis discussed in this paper is based on naphtha from the 50-50mix. Actual data was obtained for a typical operating day. Table 1 gives overall material balance for the catalytic reforming unit. The naphtha feedstock and product reformate were analyzed using GLC. Tables 2 and 3 summarize the GLC results according to lumping criterion discussed elsewhere (3). Table 4 is a detailed component and lumps distribution for all process streams. It should be emphasized here that the analysis presented in this paper is heavily dependent on the availability of such data as presented in Table 4.

4. PATTERN OF CURRENT ENERGY UTILIZATION

The required energy for the reforming process is supplied by the combustion of refinery fuel gas with typical composition as follows:

H_2	: 60.28%	C_1	: 10.08%	C_2	: 7.42%
C_3	: 11.13%	ic_4	: 3.42%	nc_4	: 6.22%
ic_5	: 1.14%	nc_5	: 0.31%		

It is worth noting here that despite the furnace arrangement shown in Fig. 1 the actual setup combines the flue gases from the three furnaces into one convection section and one stack. As a result, the radiation zones are used only for the process fluid. The flue gases are used for steam generation and superheating service in the convection section. The flue gases enter and leave the convection section at temperatures of 700°C and 400°C respectively. About 8.0-8.5 tons/hr of steam (12 Kg/cm^2, 250°C) is generated using boiler feed water at 140°C.

Part of the energy possessed by the effluent from the third reactor is recovered through heat exchange with initial charge. The remainder is given off to air and water prior to entering the separator. The energy requirement for compressing the separator gas up to reactor pressure is supplied by electrically driven compressor. The compressor is rated at about 1.68 MW. The energy requirement for the stabilizer is provided using a direct fired reboiler utilizing refinery fuel gas.

At present the quantity of fuel gas being fired in reforming reactor furnaces is not monitored while measurement of the fuel gas burned in the reboiler is available and indicate that consumption is about 220 Kg/hr.

5. ANALYSIS OF ENERGY UTILIZATION

It is quite customary that energy utilization is evaluated on the basis of the first law of thermodynamics (simple energy balance), an approach which ignores the fact that all forms of energy are not completely interchangeabel. Alternatively, second law analysis which takes into account the quality of the energy forms involved may be undertaken. Both analyses are important but second law analysis may often reduce to first law analysis with due recognition of how temperatures, pressures and compositions are degraded in the process (4,5). Furthermore, the notion of "inevitable" inefficiencies involved in chemical processes may be taken into consideration when analyzing energy utilization. This notion is quite significant in the context of chemical reactions.

In the catalytic reforming process, which is essentially endothermic, a significant quantity of direct heat is utilized to upgrade products. As a result, the catalytic reforming process utilizes only a small fraction of the energy provided by the fuel to upgrade products and generate steam. Only about 6.6% was being utilized according to one study (6). This is due mainly to :

(i) irreversibility of the chemical reactions;

(ii) high temperature heat transfer.

In addition, the combustion process itself is highly irreversible and wasteful of available energy. This is found to be so even when it is conducted in such a way that the enthalpy of combustion is retained in the combustion products. In one instance, 33% of the initial availability was found to be irreversibly lost (7).

Despite this, thermodynamic analysis is quite useful in tracing locations where "avoidable" energy losses can be identified. Furnaces, heat exchanges and distillation operations are major candidate locations.

5.1 Reforming Reaction Furances

For furnaces, the thermal efficiency is defined as:

$$\eta_1 = \frac{\text{enthalpy increase of heated fluid}}{\text{heat combusion of the fuel}}$$

or

$$\eta_1 = \frac{(ms)(\Delta H_s)}{(m\ \Delta H_c)\ \text{fuel}}$$

The availability or exergy defined as:

$$B = H - T_o S$$

can be utilized to define the process efficiency (8) as:

$$\eta_2 = \frac{(ms)(\Delta B_s)}{(mB)_{\text{fuel + air}} - (mB)_{\text{Comb.Prod.}}}$$

Based on process stream compositions shown in Table 4 and process conditions given in Fig.1., the enthalpy increase of process streams in reforming furnaces are calculated to be:

For H1 $\Delta H_s = 6.224 \times 10^6$ Kcal/hr
For H2 $\Delta H_s = 3.893 \times 10^6$ Kcal/hr
For H3 $\Delta H_s = 1.043 \times 10^6$ Kcal/hr

Composition of intermediate reactor streams are estimated using a simulation model of catalytic reforming described elsewhere (9).

Since the quantity of fuel gas used is not available, it was estimated on the basis of an energy balance around the convection section. The calculations were based on the following flue gas analysis:

8.5%:O_2 7.2%:Co_2 Balance:N_2

The corresponding theoretical and actual air to fuel ratios were found to be 17.2 and 27.3 Kg of air per Kg fuel respectively: Thus,

$$\% \text{ theoretical air} = 159\%$$

The fuel being fired was estimated to be about 1850 Kg/hr. An overall heat balance for the three furnaces is presented in Table 5. As can be seen from this Table the overall thermal efficiency is around 70%. However, the second low process efficiency is as expected only about 27%, as summarized in Table 6.

It should be remarked here that the relatively low thermal efficiency can be a attributed in part to the high stack temperature as well as the above normal excess air. Significant improvement in efficiency is possible if the present level of excess air is reduced to about 20% through proper operation and continuous monitoring of excess oxygen. This can lead to an improvement in efficiency from 70% to about 75% (10). An improvement of about 5.6% is possible if stack temperature can be reduced to about 200°C and generated extra stream in the convection section. Air preheating provides an alternative means for reducing fuel gas consumption.

5.2 Feed Effluent Heat Exchangers

The process efficiency for a heat exchanger is defined as:

$$\eta_3 = \frac{\text{output exergy}}{\text{input exergy}} = \frac{M_c(\Delta B c)}{M_h\ (-\Delta B_b)}$$

The availability change of the cold stream is computed to be around 8.37×10^6 Kcal/hr whereas the availability change of the hot stream is 11.24×10^6 Kcal/hr. Consequently $\eta_3 = 74.5\%$. This efficiency can be improved by providing greater heat exchange surface which will reduce energy losses by the effluent streams and increase the feed inlet temperature to the first heater thereby reducing fuel gas requirements. The level of added heat pick up should be assessed on the basis of technical and economic considerations.

5.3 Hydrogen Recycle Ratio

The quantity of process fluid handled by the reforming furnaces depends in part on the hydrogen/hydrocarbon recycle ratio being used. Any increase above the design ratio constitutes an additional load on the furnace and contributes to fuel wasting. For the particular operating day used in this study, the calculated ratio was found to be around 12% compared with 8% as design value.

6. CONCLUSIONS

Analysis of the energy utilization in the catalytic reforming studied in this paper has revealed the following:

- Energy is being wasted due to the large quantity of excess air used. It is of prime importance that the excess air be reduced to an acceptable level.

- Improved process efficiency is possible for the reforming furnaces through reduction of the present stack temperature (400°C). This

can be achieved either by using greater heat pickup in the convection section or air preheating, or both.

- Reducing Diluent hydrogen (H/C ratio) to the level specified by design should help energy conservation in the reforming reaction section.

- Greater heat pickup in the feed-effluent heat exchanger would improve the process effeciency of both the heaters and exchanger.

7. NOMENCLATURE

B	=	**Availability**
C	=	**Cold fluid**
H	=	**Enthalpy**
H_c	=	**Enthalpy of Combustion**
h	=	**Hot fluid**
M	=	**Mass flow rate**
M_s	=	**Mass flow rate of process stream.**
S	=	**Entropy**
T	=	**Ambient temperature**
η	=	**Efficiency**
Δ	=	**Change**

8. REFERENCES

(1) Ballut, A.A., "Heat Recovery Analysis of an existing Crude Distillation Unit", Heat Recovery Systems, Vol. 6, No. 5, pp. 361 - 367, 1986.

(2) Kashim, E., "Energy Conservation Outlook in Petroleum Refineries: Azzawia Refinery Experience", Proceedings of the Libyan - Italian Joint Seminar on Energy Issues, Tripoli, 27 - 29 October 1987.

(3) Ballut, A. et. al. "Modeling and Simulation of Catalytic Reforming Unit at Azzawia Refinery", Part II, September 1986. Unpublished Rpt.

(4) Flower, J. and Linnhoff, B., "Thermodynamic Analysis in the Design of Process Networks", Computers and Chemical Engineering, Vol. 3, pp. 283 - 291, 1979.

(5) Maloney, D. and Burton, J., "Using Second Law Analysis for Energy Conservation Studies in the Petrochemical Industry", Energy, Vol. 5, pp. 925 - 930, 1980.

(6) Kapner, R. and Lannus, A., "Thermodynamic Analysis of Energy Efficiency in Catalytic Reforming", Energy, Vol. 5, pp. 915 - 924, 1980.

(7) Sussman, M., "Steady-flow Availability and the Standard Chemical Availability", Energy, Vol. 5, pp. 793 - 802, 1980.

(8) Dealy, J. and Weber, M., "Thermodynamic Analysis of Process Efficiency" Applied Energy, Vol.6, pp. 177 - 201, 1980.

(9) Ballut, A. Et.al. "Modeling and Simulation of Catalytic Reforming Unit at Azzawia Refinery", Part III, July 1988. Unpublished Report.

(10) Energy Technology Handbook, McGaw-Hill Book Co., New York, 1977.

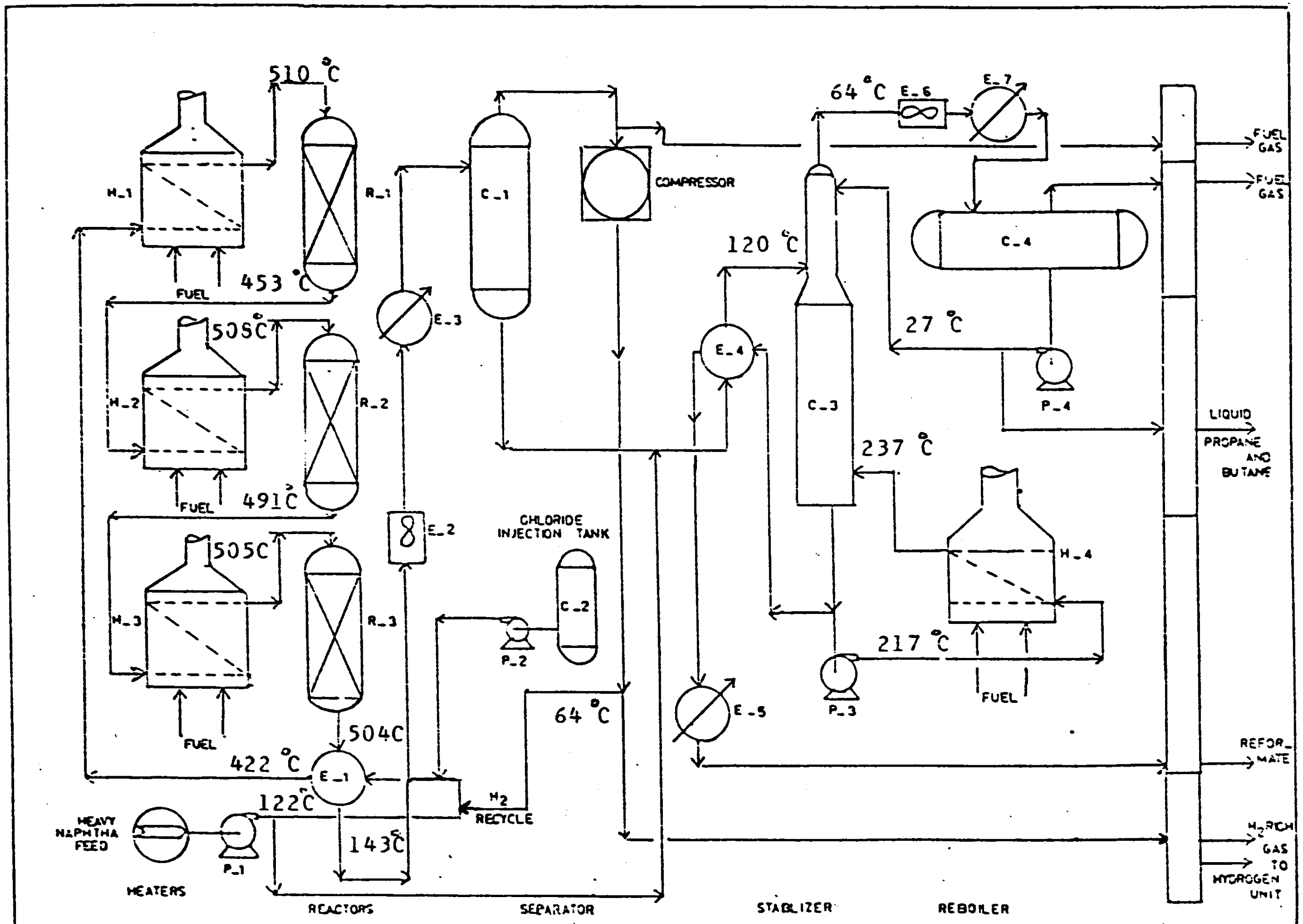


FIG 1 SEMI_REGENERATIVE UOP_PLATFOMING PROCESS AT AZZAWIA REFINERY

TABLE 1

Overall Material Balance for Catalytic Reforming Plant
(Tons/hr)

Stream	Input	Output
Naphtha	32.900	-
Reformate	-	27.893
Hydrogen	-	2.414
LPG	-	2.040
Offgas	-	0.553
TOTAL	32.900	32.900

TABLE 2

Summary of GLC Results of Naphtha

(In weight percent)

Carbon	Parafins			Naphthenes			Aromatics	Total
	Iso	Normal	Total	pentanes	hexanes	Total		
6	6.14	6.97	13.11	3.75	2.42	6.17	-	19.28
7	7.12	7.08	14.20	8.53	6.91	15.44	0.73	30.37
8	13.83	6.57	20.40	1.12	4.45	5.57	2.03	28.00
9	8.27	4.58	12.85	-	5.03	5.03	-	17.88
10	2.26	0.37	2.63	-	1.84	1.84	-	4 47
11								
Total	7.62	25.57	63.19	13.40	20.65	34.05	2.76	100.00

TABLE 3

Summary of GLC Results of Reformate

(In weight percent)

Carbon	Parafins			Naphthenes			Aromatics	Total
	Iso	Normal	Total	pentanes	hexanes	Total		
4	-	4.02	4.02	-	-	-	-	4,02
5	5.27	3.38	8.65	1.22	-	1.22	-	9.87
6	11.30	5.38	16.68	1.59	-	1.59	4.91	23.18
7	6.78	2.50	9.28	1.18	0.25	1.43	15.46	26.17
8	2.60	0.68	3.28	0.12	-	0.12	19.06	22.46
9	0.4	0.13	0.53	-	-	-	12.97	
10	-	0.80		-	-	-	-	14.30
Total	26.35	16.89	43.24	4.11	0.25	4.36	52.40	100.00

TABLE 4

Stream Compositions, Weight Per Cent.

Component	Naphtha	Recycle	Naphtha + Recycle	3rd Reactor Effluent	Seperator Gas	Seperator Liquid	Debut. Liquid	Debut. off Gas	Reformate
H_2		24.72	11.75	12.70	24.72	0.03	-	1.66	-
C_1		24.47	11.63	12.73	24.47	0.35	0.71	16.61	-
C_2		27.51	13.08	14.72	27.51	1.12	8.87	28.93	-
C_3		13.25	6.63	8.44	13.25	3.36	40.03	37.68	-
iC_4		5.73	2.72	4.18	5.73	2.54	35.14	10.54	-
nC_4		4.32	2.05	4.54	4.32	4.78	15.25	4.78	4.02
iC_5		-	-	2.34		4.82	-	-	5.27
nC_5		-	-	1.50		3.09	-	-	3.38
IP	37.62	-	19.74	9.38		19.29	-	-	21.08
NP	25.57	-	13.42	4.22		8.68	-	-	9.49
N_5	13.40	-	7.03	1.83		3.76	-	-	4.11
N_6	20.65	-	10.84	0.11		0.23	-	-	0.25
A	2.76	-	1.44	23.31		47.95	-	-	52.40
TOTAL	100	100	100	100	100	100	100	100	100

TABLE 5

Overall Heat Balance for Reforming Furnaces

Description	Heat: KCal/hr	%
Input:		
Burning of fuel	22.8×10^6	100%
Output:		
Process Heat Gain	11.16×10^6	48.78
Steam Generation	4.71×10^6	20.59
Heat Loss in Stack $T_s = 400^oC$	2.68×10^6	11.71
(Heat Loss in Stack) ($T_s = 200^oC$)	(1.25×10^6)	
Unaccounted Heat Loss (by difference)	4.33×10^6	18.92
TOTAL	22.88×10^6	100.00

TABLE 6

Availability Analysis of Reforming Furnaces

Stream	Availability charge, KCal/hr
Process Fluid	3.72×10^6
Steam Generation	1.98×10^6
Combusion of fuel	20.83×10^6
η_2	0.27

In the name of God, Most Gracious, Most Merciful

MATERIAL ENDURANCE MODELLING FOR ENERGY CONSERVATION

Dr. Mohamed El-Shayeb

Mechanical Engineering Department

Al-Fateh University, Tripoli, Libya

ABSTRACT

The situation of energy demand and supply in the world in the present time and in future is quite critical. It appears unquestionable that exponential growth in oil and gas production will soon be arrested. Major action will have to be taken to decrease the consumption of gas and oil in district heating purposes.

The advances in computer technology have led to new approaches to improve building materials, e.g. steel, concrete, composite, wood, fiber, insulation, etc. Using the computer it is possible to describe the growing of heat and the heat endurance response of structural members. Designers will eventually be able to optimize building materials systems for improved insulation.

This paper is primarily aimed at developing the flexible design procedures for heat resistive material structurals. These tools will help the construction industry respond to changes in materials engineering. These design procedures will help the architects and engineers to select building materials for good efficiency and design flexibility.

In this paper, the development of flexible heat resistance design procedures involves three types of models, heat transfer, structural-heat transfer interface, and structural system models [1] . These three models are combined to obtain an overall heat endurance model. The heat transfer models are used to define temperature profile within the assembly and the thermal degradation of the material at each time step. The structural-heat transfer interface models take the temperature and mass loss data as input and produce the appropriate structural properties of the structural components. These structural properties are used as input to the structural system models that define the structural performance of the assembly or member. The significance of this program comes from the fact that energy consumption will be lowered and the material properties will be improved. Also a heat transfer mathematical model has been developed and presented in totality in this paper.

INTRODUCTION

An abundance of new structural material products have been introduced in recent years. Their introduction into markets that require heat rated insulation of the assemblies has not been taken into consideration for energy conservation.

Flexible design procedures based on mechanistic models can maximize the benefits of changes in material structurals. These models promote insulation efficiency and design flexibility in engineered material structures. These models support the development of new heat-rated insulation components and assemblies that are suitable for energy conservation. These flexible design procedures allow the components to be described in terms of individual performance criteria. This will support the substitution of products that meet the individual performance criteria.

APPROACH

To develop flexible heat-rated insulation design procedure which effectively respond to changes in material structurals. This procedure will involve development of three mathematical models as indicated in flow chart (Fig. 1),and as described below [2] .

(1) Heat Transfer Model

The heat transfer model will be used to predict the temperature history of the material member or assembly at each time interval. Flow chart(Fig. 2) summarises the input and output data of this model.

(2) Structural Model

The structural model will be used to predict the structural performance of the member or assembly as shown in flow chart(Fig. 3).

(3) Structural Heat Transfer Interface Model

The output data of this model are the structural properties, new thermal capacity, thermal conductivity, moisture content,...etc. at each new time step. The diagram outlines of this model will be explained in flow chart (Fig. 4).

Heat Endurance Model

The combination of the above three models will result in heat endurance model as shown in flow chart (Fig. 5). Hereinafter, heat transfer mathematical model will be developed as an important part of heat endurance model.

HEAT TRANSFER MATHEMATICAL MODEL FOR CONCRETE-FILLED SQUARE STEEL COLUMN

In this heat transfer mathematical model, the calculation of temperature history of a concrete-filled square steel columns, for which no method exists at present [1] is developed. This mathematical model can be used to modify the thermal conductivity and thermal capacity of the material to maximize its energy conservation properties.

Division of Cross-Section into Elements

The column temperatures are calculated by using the finite difference method [3]. The cross-sectional area of the column is subdivided into a number of elements, arranged in a triangular network Fig(6) and (7).

Temperature Calculations

It will be assumed that the columns are exposed on all sides to the heat of a fire whose temperatuer course follows that of the standard fire described in Reference [1]. This temperature course can be approximately described by the following expressions

$$T_f^j = 20 + 750 \left[1 - \exp(-3.79553\sqrt{t})\right] + 170.41\sqrt{t} \qquad (1.1)$$

where t is the time in hours and T_f^j is the fire temperature in $^{\circ}C$ at time $t = j\Delta t$.

Equations at Fire/Steel Boundary

The temperature rise in each element can be derived by making a heat balance for it, i.e. by applying the parabolic unsteady state, partial differential equation and its numerical solution, described in Referenece[1] into the region. Also, the heat transfer by radiation to the surface boundary elements must be considered as follows.

Heat Transfer by Radiation

The heat due to the temperature course of Eqn.(1.1) will be transmitted from the fire to an elementary surface region, $R_{m,n}$ by radiation. For the fire/steel boundary, the heat transmitted by radiation along the boundary A-B (see Figure 8) during the period $j\Delta t < t < (j+1)\Delta t$ for a unit height of the column can be found as explained in Reference No. [1] as:

$$q_R = A_{es}\,\sigma\,\epsilon_f\,\epsilon_s \left[(T_f^j + 273)^4 - (T_{m,n}^j + 273)^4\right] \qquad (1.2)$$

Where

q_R = heat transfer by radiation, J/(m.hr)

A_{es} = surface area of the fire/steel boundary element i.e.

A_{es} = 2 (Δh_g)(1.0), m

σ = Stefan-Boltzman constant, $J/(hr.m^2.K^4)$

ϵ_f, ϵ_s = as defined in reference [1], Chapter (3), dimensionless.

T_f^j = fire temperature, K^4

Heat Transfer by Conduction

From the surface region $R_{(m,n)}$ along the boundary line A-B as illustrated in Figure (8), heat is transfer by conduction to the two neighbouring regions, $R_{(m+1,\ n-1)}$ and $R_{(m+1,n+1)}$ [1, 4]. The fire/steel boundary equation can be obtained by adding all heat gained and losses, the final equation is :

$$T^{j+1}_{(m,n)} = T^{j}_{(m,n)} + \frac{\Delta t}{(\rho_s C_s)_{m,n}(\Delta h_g)^2}$$

$$\left\{\left[\frac{K^{j}_{s(m+1,n-1)} + K^{j}_{s(m,n)}}{2}\right]\left[T^{j}_{(m+1,n-1)} - T^{j}_{(m,n)}\right] + \left[\frac{K^{j}_{s(m+1,n+1)} + K^{j}_{s(m,n)}}{2}\right]\left[T^{j}_{(m+1,n+1)} - T^{j}_{(m,n)}\right] + (A_{es}\,\sigma\,\epsilon_f\,\epsilon_s)\left[(T^{j}_{f} + 273)^4 - (T^{j}_{(m,n)} + 273)^4\right]\right\} \qquad (1.3)$$

Equations for Inside Steel Region

In the same way as for elementary regions at the outer boundary, the temperature inside steel region can be calculated by writing heat balance equation for the inside elementary regions. For the elements in the steel, Figure (9), except for the boundary elements, the temperature rise at time $t = (j + 1)\,\Delta t$, is given by

$$T^{j+1}_{(m,n)} = T^{j}_{(m,n)} + \frac{\Delta t}{(\rho_s C_s)^{j}_{(m,n)}(\Delta h_g)^2}$$

$$\left\{\left[\frac{K^{j}_{s(m-1,n-1)} + K^{j}_{s(m,n)}}{2}\right]\left[T^{j}_{(m-1,n-1)} - T^{j}_{(m,n)}\right] + \left[\frac{K^{j}_{s(m-1),(n+1)} + K^{j}_{s(m,n)}}{2}\right]\left[T^{j}_{(m-1,n+1)} - T^{j}_{(m,n)}\right] + \left[\frac{K^{j}_{s(m+1,n-1)} + K^{j}_{s(m,n)}}{2}\right]\left[T^{j}_{(m+1,n-1)} - T^{j}_{(m,n)}\right] + \left[\frac{K^{j}_{s(m+1,n+1)} + K^{j}_{s(m,n)}}{2}\right]\left[T^{j}_{(m+1,n+1)} - T^{j}_{(m,n)}\right]\right\} \qquad (1.4)$$

Equations for Steel/Concrete Boundary

For the elements at the boundary between the steel and concrete as illustrated in Figure 10) the temperature rise at time $t = (j+1)\,\Delta t$ is:

$$T^{j+1}_{(m,n)} = T^{j}_{(m,n)} + \frac{\Delta t}{\left[(\rho_s C_s)^{j}_{(m,n)} + (\rho_c C_c)^{j}_{(m,n)} + (\rho_w C_w \Phi)^{j}_{(m,n)}\right](\Delta h_g)^2}$$

$$\left\{\left[\frac{K^{j}_{s(m-1,n-1)} + K^{j}_{s(m,n)}}{2}\right]\left[T^{j}_{(m-1,n-1)} - T^{j}_{(m,n)}\right] + \left[\frac{K^{j}_{s(m-1,n+1)} + K^{j}_{s(m,n)}}{2}\right]\left[T^{j}_{(m-1,n+1)} - T^{j}_{(m,n)}\right]\right.$$

$$+\left[\frac{K^j_{c(m+1,n-1)}+K^j_{c(m,n)}}{2}\right]\left[T^j_{(m+1,n-1)}-T^j_{(m,n)}\right]$$
$$\left.+\left[\frac{K^j_{c(m+1,n+1)}+K^j_{c(m,n)}}{2}\right]\left[T^j_{(m+1,n+1)}-T^j_{(m,n)}\right]\right\} \tag{1.5}$$

Where

$\Phi^j_{(m,n)}$ = the concentration of moisture content

Equations for Inside the Concrete Region

For the elements in the concrete as illustrated in Figure (11), except for the elements at the boundary between the concrete and steel, the temperature rise at time $t = (j+1)\Delta t$, is given by

$$T^{j+1}_{(m,n)} = T^j_{(m,n)} + \frac{\Delta t}{\left[(\rho_c c_c)^j_{(m,n)} + (\rho_W c_W \Phi^j_{(m,n)})\right](\Delta h_g)^2}$$
$$\left\{\left[\frac{K^j_{c(m-1,n-1)}+K^j_{c(m,n)}}{2}\right]\left[T^j_{(m-1,n-1)}-T^j_{(m,n)}\right]\right.$$
$$+\left[\frac{K^j_{c(m-1,n+1)}+K^j_{c(m,n)}}{2}\right]\left[T^j_{(m-1,n+1)}-T^j_{(m,n)}\right]$$
$$+\left[\frac{K^j_{c(m+1,n-1)}+K^j_{c(m,n)}}{2}\right]\left[T^j_{(m+1,n-1)}-T^j_{(m,n)}\right]$$
$$\left.+\left[\frac{K^j_{c(m+1,n+1)}-K^j_{c(m,n)}}{2}\right]\left[T^j_{(m+1,n+1)}-T^j_{(m,n)}\right]\right\} \tag{1.6}$$

Stability Criterion

In order to ensure that any error existing in the solution at some time level will not be amplified in subsequent calculations, a stability criterion has to be satisfied which, for a selected value of Δh_g, limits the maximum of the time step (Δt). Following the method described in reference [1], it can be derived that for the fire-exposed column the criterion of stability is most restrictive along the boundary between fire and steel. It is given by the condition

$$\Delta t < \frac{2\,(\Delta h_g)^2\,(\rho_s\,c_s)_{min}}{4K_{s(max)} + 4(\Delta h_g)h_{max}} \tag{1.7}$$

Where the maximum value of the coefficient of heat transfer during exposure to the standard fire (h_{max}) is approximately 3×10^6 J/m^2h^oC [1].

Effect of Moisture

The effect of moisture in the concrete elements is taken into account by assuming that in each element, the moisture starts to evaporate when the temperature of the element reaches 100°C (212 °F). During the period of evaporation all the heat supplied to an element is used for evaporation of the moisture, until the element is dry[1].

Computer Program

A comprehensive computer program for this mathematical model has been developed with the verification of final results as presented in Reference No. [1].

NOMENCLATURE

C	Specific heat (J/Kg °C)
h	Coefficient of heat transfer at fire exposed surface (W/m^2 °C)
K	Thermal conductivity (W/m °C)
T	Temperature (°C)
ϵ	emissivity
ρ	density (Kg/m^3)
σ	Stefan-Boltsmann constant ($W/m^2\ K^4$)
t	time (h)
ϕ	Concentration of moisture

SUBSCRIPTS

o	at room temperature
c	of concrete
f	of the fire
m	at the points m in column
max	maximum
min	minimum
n	at the point in a row
s	of steel
T	Pertaining to temperature

SUPERSCRIPTS

j	at $t = j \Delta t$

REFERENCES

[1] El-Shayeb, Mohamed, Fire Resistance of Concrete-Filled and Reinforced Concrete Columns, Ph.D. Thesis, University of New Hampshire, Durham, New Hampshire, U.S.A, 1986.

[2] El-Shayeb, Mohamed and et al, Fire Endurance Modeling, Forest Products Research Society, 42nd Annual meeting, Quebec, Canada, 1988.

[3] Dusinberre, G.M. Heat Transfer Calculations by Finite Differences, International Textbook Company, Scranton, PA, 1961.

[4] El-Shayeb, Mohamed, A Model for Predicting Weld Hardness, Master Thesis, Carleton University, Ottawa, Canada, 1981.

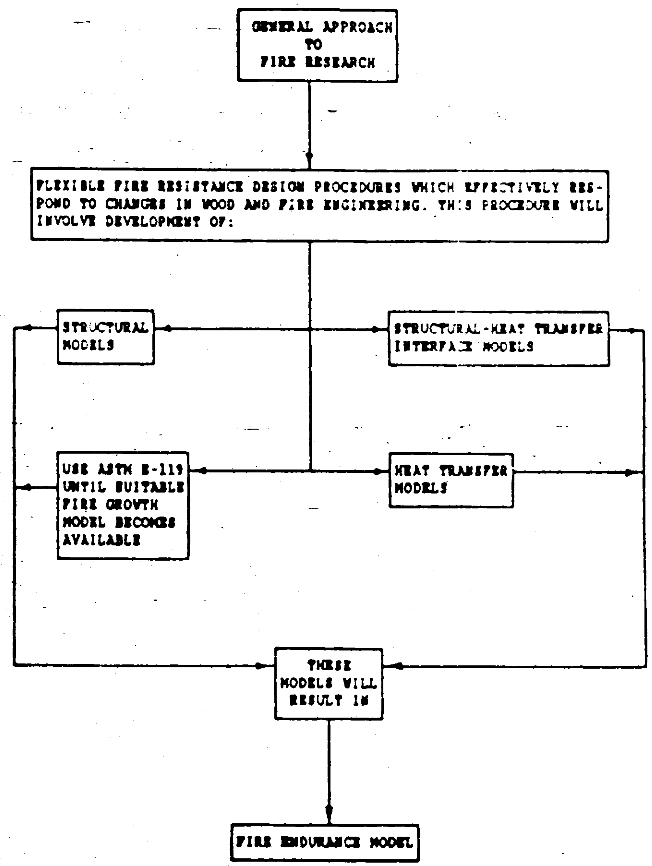


Figure 1.

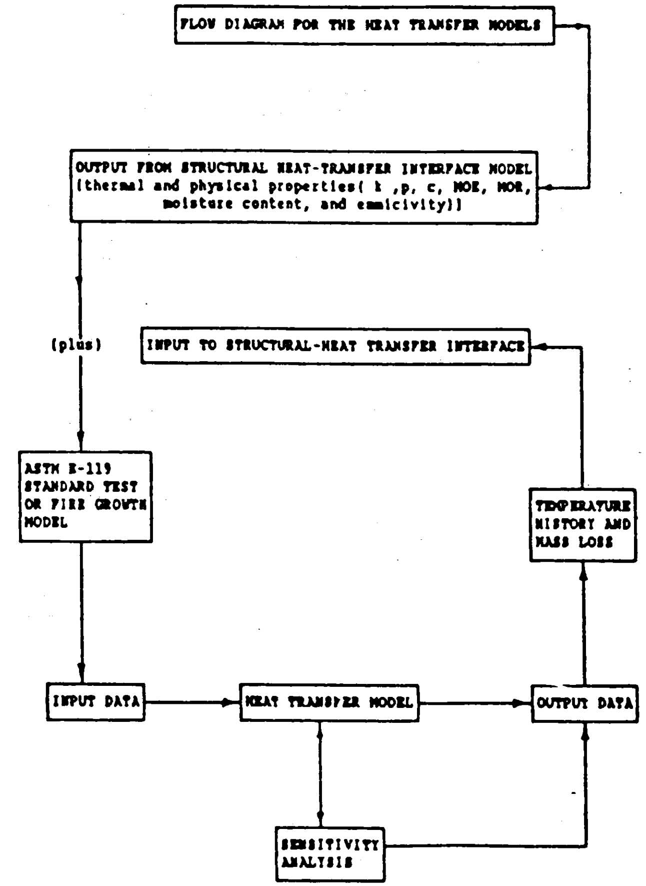


Figure 2

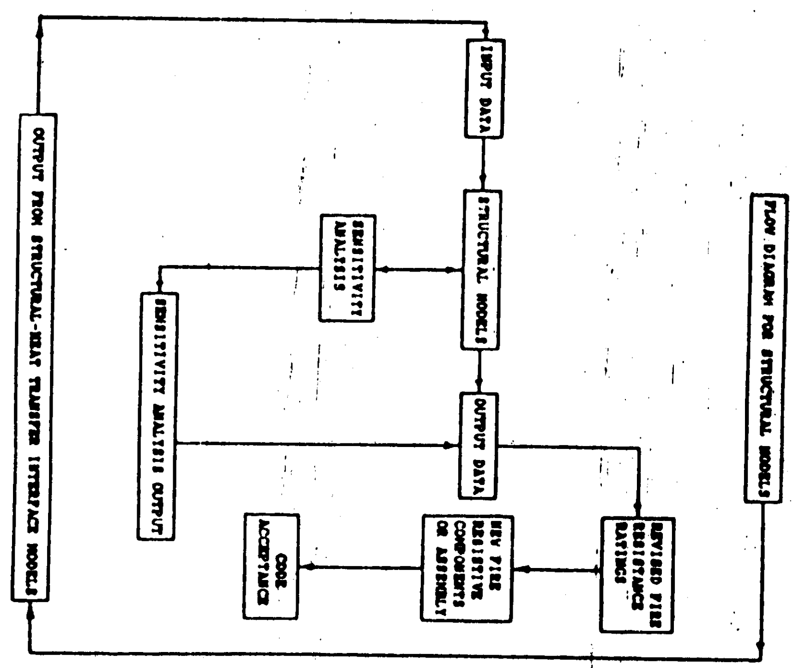


Figure 3

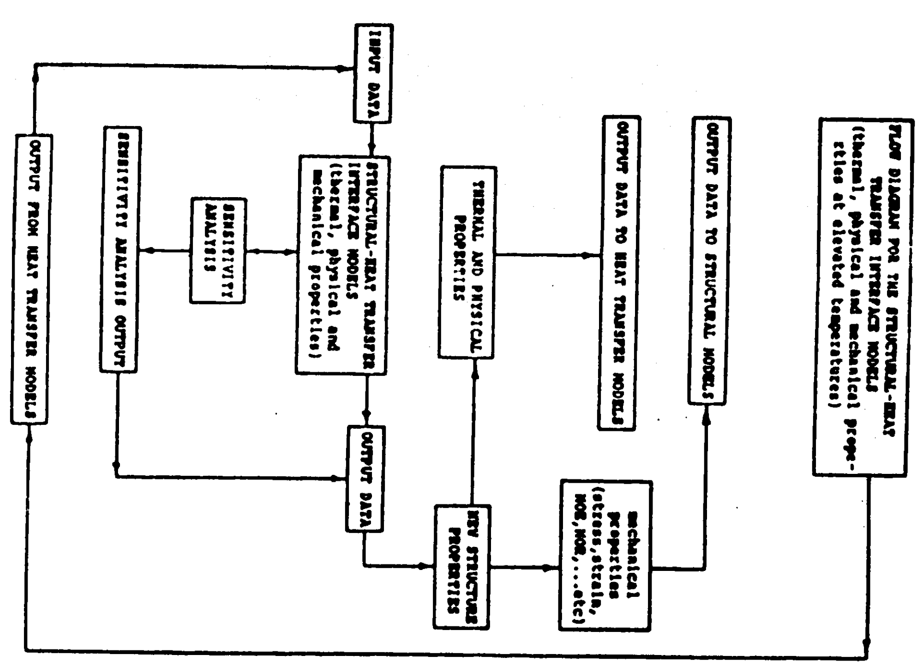
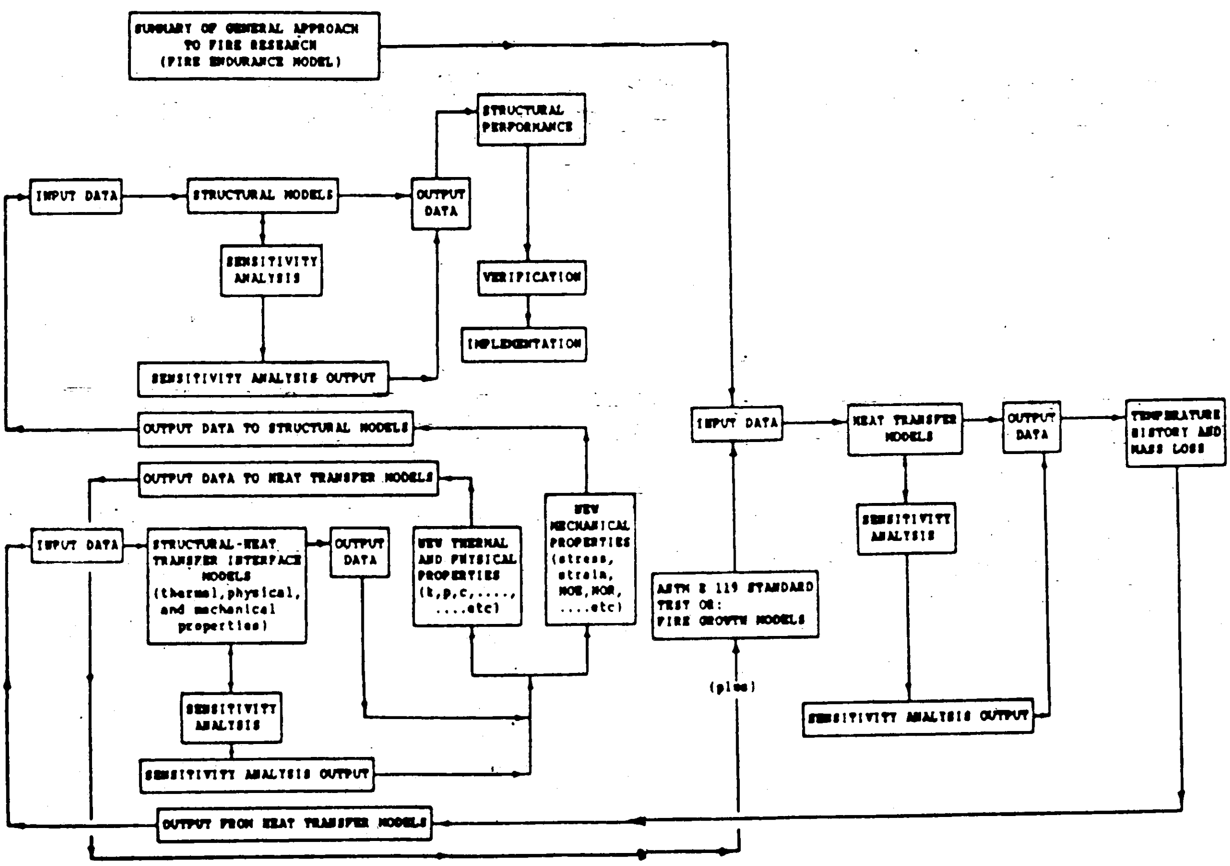


Figure 4.

Figure 5.



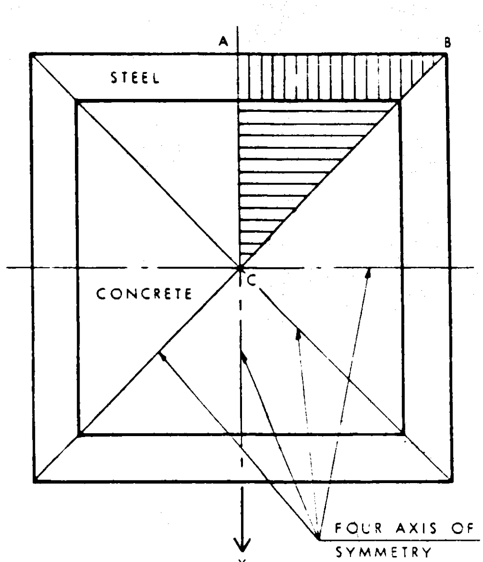


FIGURE 6

COLUMN CROSS-SECTION

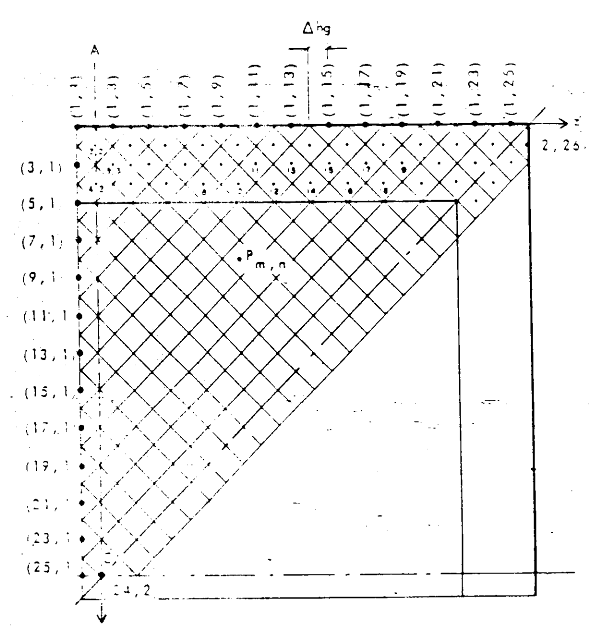


FIGURE 7

TRIANGULAR NETWORK OF ELEMENTS IN A ONE-EIGHTH SECTION OF COLUMN

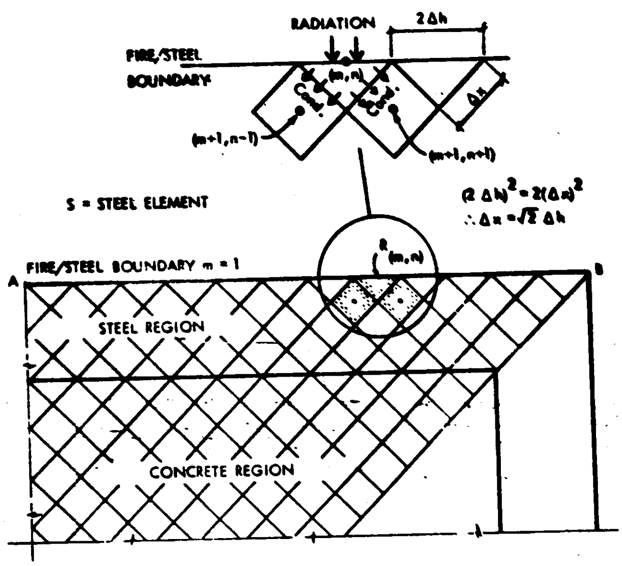


FIGURE 8
FIRE/STEEL BOUNDARY REGION

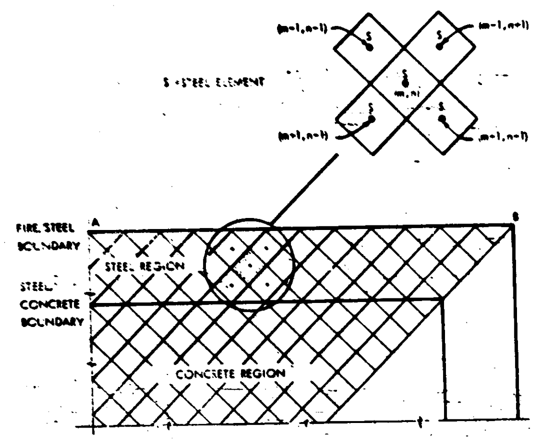


FIGURE 9
INSIDE STEEL REGION

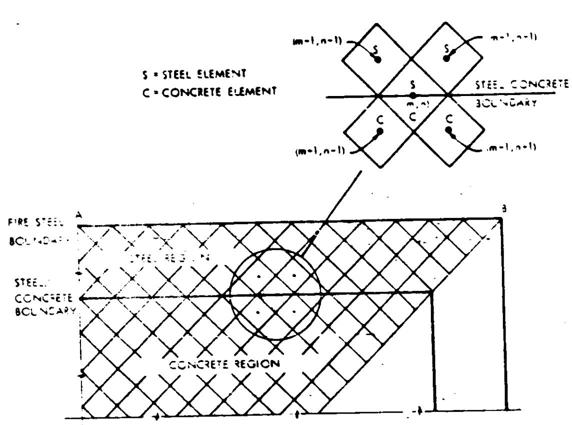


FIGURE 10
STEEL/CONCRETE BOUNDARY

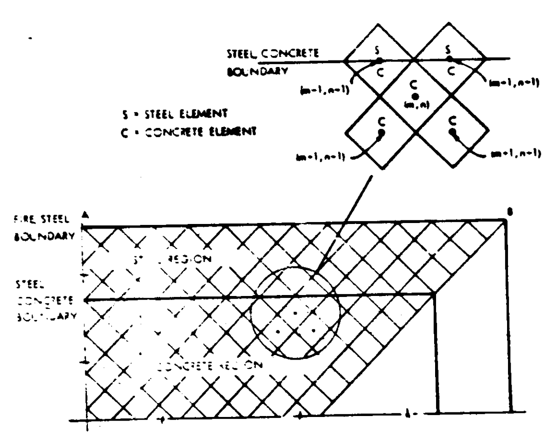


FIGURE 11
INSIDE CONCRETE REGION

الطاقة المستهلكة فى استخلاص الألومنيوم تحت الظروف المتوفرة بالجماهيرية

سليمان يونس قجم
وحدة بحوث هندسة وعلوم المواد
مركز بحوث العلوم الهندسية

ملخص البحث :

تعتبر الطاقة والخام من أهم العوامل المتحكمة فى انتاج الألمونيوم فى العالم ، ونظرا لعدم توفر خام البوكسايت محليا وهو المصدر الرئيسى لصناعة هذا الفلز ، فقد اتجه البحث نحو امكانية استخلاص الألمونيوم من مادة بديلة وهو الكاولين المتوفر محليا وبكميات اقتصادية . وقد وضعت دراسة مقارنة من ناحية الطاقة المستهلكة بين الخام الوطنى عند استعمال حامض الهيدروكلوريد من مصنع أبو كماش والبوكسايت المستورد بصورة مصنعة على شكل إلومنا (لو٢أ٣) .

خ اعطت الدراسة نتائج جيدة خاصة عند اضافة مادة الفورايد الموجودة داخل خام الاباتايت مما قلل من الطاقة المستهلكة فى عملية التحميض حيث كانت نسبة الاستخلاص حوالى ٩٨ / فى مدة ٣٠ دقيقة .

مقدمـــة :-

يعد الألومنيوم أكثر الفلزات تواجدا فى القشرة الأرضية اذ يكون ما يقرب من ١/١٢ من مجموعها . بينما يكون الحديد الذى يأتى بعده فى الترتيب ١/٢٠ منها . وبالرغم من ذلك فان الانسان لم يتمكن من استخلاصه بشكل مستقل الا منذ مائة عام فقط . وقد أصبح الالومنيوم عنصرا أساسيا فى حياة الانسان سواء أكان ذلك فى المجتمعات المتقدمة صناعيا أو فى مجتمعات البلدان النامية فى مختلف القطاعات كالانشاءات والنقل والكهرباء وصناعة الأثاث والتقنية والأسلحة وصناعة الفضاء ... الخ . وذلك كله راجع الى ما يتمتع به الالومنيوم من مزايا وصفات فريدة والتى منها خفة وزنه وجودة توصيله للحرارة والكهرباء وسهولة تشكيلة ومقاومته للتآكل . (١)

ويتواجد الألومنيوم فى الطبيعة على شكل تمعدنات مختلفة أهمها البوكسايت ويحتوى على حوالى ٥٤ / الومنا ، والكاولين (الصلصال) ويحتوى على ٣٩ / الومنا . ويستخرج الالومنيوم فى معظم مناطق العالم من البوكسايت ، وقد ابتدء

في استخراجه من خام الكاولين • ويقدر الإقتصاديون في العالم بأن احتياطي البوكسايت قد يكفي الى ما يقرب من ٦٠ سنة وذلك في حالة استمرار معدلات النمو الحالية • ولم تشر نتائج المسح الجيولوجي لليبيا والوطن العربي الى تواجد البوكسايت عدا السعودية والسودان مؤخرا بينما تؤكد على وجود خام الكاولين في ليبيا • وبالذات في مناطق سبها وجبل نفوسة وكذلك في مناطق عديدة من العالم من بينها الدول العربية • وليس هناك اية بوادر للقيام باستيراد البوكسايت وتكرير الآلوميتا من قبل الدول العربية المنتجة للألومنيوم وذلك لعدم وجود استيراتيجية عامة شاملة لهذا الموضوع ، ومع هذا فقد حصلت مبادرات تخدم نفس الهدف وهو توفير مصدر مملوك ولو جزئيا لمشاريع الالومنيوم التي كانت مخططة • (٢) •

ولهذه الغاية فقد ساهمت كل من مصر وليبيا والكويت والعربية السعودية ودولة الامارات العربية بتأسيس شركة مع الحكومة الغينية باسم الشركة الغينية العربية للالومينا والالومنيوم (ALGAE) وبالتعاون مع شركة الوسويس التي قامت باعداد دراسة الجدوى للمشروع عام ١٩٧٨/٧٧م وتقدر طاقة المشروع من البوكسايت بـ ٩ ملايين طن سنويا مخصص منها للتصدير ٥ر١ مليون طن (٣) ، كما أن هناك شركتان أخرتان احدهما بين الجزائر والحكومة الغينية لانتاج البوكسايت في دابولا (DAPOLA) واخرى بشراكة مع الأقطار العربية وحكومة غنيا وشركة الوسويس باسم (ALOSWISS) وفي المقابل فان شركات الالومنيوم الكبرى والمؤسسات البحثية ودول العالم الأخرى تقوم بمحاولات جادة في سبيل ايجاد خام بديل عن البوكسايت في حال نفاذه -متوفر محليا - وقد برز خام الكاولين كأحد هذه البدائل وهو موضوع هذه الدراسة ، وتعتبر الطاقة أهم العوامل المتحكمة في استخلاص الالومينا على الاطلاق وبالتالي الاستفادة منه كبديل عن المعادن الأخرى بما له من صفات متميزه ، ويعتبر الغاز من أهم مصادر الطاقة في انتاج الالومنيوم وهي أحد الطرق التي يمكن بيعه بها بدلا عن تسويقه بأسعار منخفضة (٤) ويدخل في صناعة الالومينا عدد من المواد الاولية المساعدة أهمها الكوك النفطي، الكربولايت ، الزفته ، الحجر الجيري ، والفلورسيار وفلوريد الألومنيوم ، والمياه وجميع هذه المواد تستورد من خارج الوطن العربي رغم توفرها محليا •

١- استخلاص الألومنا من الخام :-

١-١ استخلاص الالومنا من خام البوكسايت :-

نظرا لارتفاع نسبة اكسيد الحديد في الخام ١٢ / ولذوبان الحديد في الأحماض فقد تعذر استعمال أحد الاحماض القوية المعروفة مثل حامض الكبريتيك أو حامض الهيدروكلوريك في استخلاص الالومنا من خام البوكسايت • ولذا فان المادة المستعملة هي مادة هيدرواكسيد الصوديوم " ص أ يد " القاعدية حيث أنها تذيب الالومنا وتترك الحديد على شكل راسب ، ويعتبر فصل الحديد من الالومنا من القضايا الهامة جدا وذلك نظرا لخواصة المغايره مثل الكثافة النوعية ومقاومة التآكل وخاصة التوصيل الكهربائي والحراري ،

ويمر البوكسايت عند تكريره بخمسة مراحل لغرض استخلال الالومنا منه وهي :

أ – عملية الطحن .

ب – عملية الهضم داخل الصودا الكاوية الساخنة .

ج – التحليل وفصل الشوائب (الطين الأحمر) عن طريق الترسيب والغسيل والتصفية .

د – عملية الترسيب وفي هذه العملية تتحلل ألومينات الصوديوم وينتج هيدرواكسيد الالومنيوم وتحتاج هذه الخطوة الى مصدر مائي كبير وثابت .

هـ – عملية تكليس الالومنا تحت درجة حرارة حوالي ٩٨٠ م للتخلص نهائيا من الماء ولتحويل الالومينا الى صورة بللورية حتى لا تترطب في الهواء وتعود الى صورة الهيدرواكسيد .

وبالاضافة الى البوكسايت فان تكرير الالومينيوم يحتاج من ٩٠ الى ١٨٠ كجم من الصودا الكاوية لكل طن من الالومنا ومن صفر الى ١٥ كجم كلس محروق ومن ٣ر٠ الى ٦ر٠ طن زيت وقود أو ما يعادله من الغاز وتحتاج العملية الى ١٥ متر مكعب من المياه لكل طن من الألومنا ، أما استهلاك الطاقة الكهربائية فانه يتراوح ما بين ٢٥٠ ك •و• لكل طن واحد حتى تكون الالومينا جاهزة للاستعمال داخل المصهر الكهربائي .

٢–١ استخلاص الالومنا من خام الكاولين :.

تعتبر عملية استخلاص الالومنا من خام الكاولين من العمليات الصناعية الحديثة جدا ولم تطبق على مستوى صناعي الا في مناطق محدودة جدا من العالم وهي لازالت قيد الدراسة والبحث كبديل عن خام البوكسايت الذى يقدر احتياطه بـ ٦٠ سنة طبقا لمعدلات نمو الاستهلاك الموجودة الآن . ويتواجد خام الكاولين باحتياطي صناعي بمناطق سبها وجبل نفوسة ، وقد تم اجراء بعض التجارب المعملية عن هذا الخام الوطني في الجامعة ومركز البحوث الصناعية وقد كان من بين نتائج هذا البحث ما يلي :

أ – استخلاص الالومنا من كاولين سبها الغير مكلس وباستعمال حامض الهيدروكلوريك عند درجة حرارة ٩٥م داخل مفاعل كيميائي سعة $\frac{1}{2}$ لتر وقد كانت النتيجة ١٢٪ الومنا فقط وبعد ساعتين من التقليب كما في شكل رقم (١) .

ب – استخلاص الالومنا من نفس الخام بعد تحميصه في درجات حرارة ٤٢٥م و ٥٤٠م باستعمال حامض الهيدروكلوريك عند درجة حرارة ٩٥م وباستعمال نفس المفاعل وبنفس سرعة الدوران وقد كانت النتائج هي ٤٥ ٪ ، ٩٠ ٪ ٩٨ / على التوالي كما في شكل رقم (٢) .

ج – استخلاص الالومنيوم من الكاولين الغير مكلس في حامض الهيدروكلوريك تحت نفس درجة الحرارة ونفس المفاعل وباستعمال الفلورايد أيون كمادة معجلة للتفاعل دون الدخول فيه وكبديلة عن عملية الكلسنة التي تعتبر أحد المصادر الكبيرة في استهلاك الطاقة ، وقد أعطت النتائج حوالي ٨٥ / الومنا في نفس الزمن ، كما في شكل (٣) .

وتمر عملية استخلاص الالومنا من الكاولين بالمراحل الآتية :-

أ - الطحن والغربلة والتصنيف للخام .

ب - التحميص في درجة حرارة ٥٤٠م على الأقل .

جـ - عملية الهضم داخل محلول أحد الأحماض القوية مثل يد كل وتحت درجة حرارة ٩٥م .

د - عملية التصفية وفصل المحلول عن الراسب وفي هذه الحالة السيليكا .

هـ - عملية فصل أيونات الألومنا التي تذوب بشحنه مغايره عن أيونات الحديد باستخدام الكيروسين .

و - عملية اعادة البلورة تحت درجة حرارة ١٠٠٠م وتكون بللورات لو$_٢$ أ$_٣$. وبذلك تكون الالومنا جاهزة للاستعمال داخل المصهر الكهربائي .

٢- مقارنة عمليتي استخلاص الالومنا :-

وبمقارنة خطوات استخلاص الالومنا من البوكسايت والكاولين نجد أن العمليتان تختلفان اختلافا كليا للأسباب الآتية :

٢-١ نسبة السيليكا عالية جدا في الكاولين ٥٤ ٪ عنها في البوكسايت ١٢ ٪ ، ولذا لا يمكن استعمال المحلول القلوي في الكاولين الذي يذيب قدرا من السيليكا مع الالومنا الأمر الذي يتسبب في احتواء السيليكا للألومنا وفقدانه وبالتالي فقد استعمل حامض الهيدروكلوريك الذي يؤدي الى اذابة الالومنا وترسيب السيليكا .

٢-٢ نسبة الحديد في البوكسايت عالية نسبيا ٤ر١١ ٪ عنها في الكاولين ٥ر١ ٪ ويتم فصل الحديد من الكاولين باذابته مع الالومنا ولكن بشحنه مغايرة (سالبة)، بينما يفصل في البوكسايت كراسب .

وبالنظر الى الخطوات السابقة نجد أنه من المحتم اقامة مصنع بمواصفات مختلفة عنها في مصانع البوكسايت مما قد يؤدي الى قفل المصانع القديمة وازدياد التكلفة بالنسبة للدول التي تمتلك هذه الصناعة من قبل .

٣- أهمية استخراج الالومنا من الخامات الوطنية :(٥)

من الدراسة السابقة نجد أن التفكير في ادخال هذا الخام المحلي في الصناعة والاستفادة منه من الأهمية بمكان وذلك نظرا للظروف الآتية :-

٣-١ الأهمية الاستراتيجية لهذا الفلز .

٣-٢ انعدام البوكسايت في الجماهيرية والوطن العربي مما يؤكد ضرورة الاعتماد على الدول الأخرى في هذا المجال .

٣-٣ تواجد خام الكاولين في الجماهيرية ومناطق أخرى من الوطن العربي .

٣-٤ تاميم الدول المالكة للبوكسايت لمناجمها وبالتالي بيعه على شكل الومنا مصنعة وباهظة الثمن كما في مخطط مصهر زوارة ودول الخليج العربي .

٣-٥ ازدياد الطلب الكبير على الالومنا لدخوله في تطبيقات صناعية كثيرة وذلك لصفاته المتميزة .

٣-٦ امكانية قيام صناعات جانبية جيدة في مجال الخزف حول الكاولين بعد استخلاص الالومنا منه .

٣-٧ استغلال النواتج الثانوية لبعض المصانع الأخرى مثل مصنع أبو كماش كحامض الهيدروكلوريك .

٣-٨ عدم وجود مصانع لاستخلاص الالومنا من البوكسايت بالطريقة القاعدية الأمر الذى يؤدى الى قفلها وفقدانها في حالة استعمال الكاولين كمصدر للألومنا .

٣-٩ ازدياد أسعار الالومنا المطرد وذلك لزيادة الطلب عليه .

٣-١٠ استعمال حامض الهيدروفلوريك كمعجل للتفاعل داخل المحلول من الممكن الاستفاده منه مرة أخرى في تصنيع الكريولايت المستعمل داخل الخلية الكهربائية بدلا من شرائه بصورة مصنعة رغم ارتفاع ثمنه .

٣-١١ تعتبر حبيبات الالومنا الناتجه عن الكاولين أكبر حجما منها عن الحبيبات الناتجة عن البوكسايت مما يسهل عملية التصفية وبالتالى تقليل تكلفة الاستخلاص .

٣-١٢ تحتاج عملية غسيل الطين الأحمر الناتجة عن ارتفاع نسبة الحديد ١٢٪ في البوكسايت الى مصدر مائى كبير بينما لا توجد ضرورة لذلك في الكاولين .

وبالنظر الى توفير المصانع التى لها علاقة بهذه الصناعة كمصنع الخزف بغريان ومصنع أبو كماش بالقرب من المصهر المرتقب في زوارة لذا فانه من الممكن جدا استغلال النواتج الثانوية من الكاولين وكذلك استعمال بعض النواتج لمصنع أبو كماش في استخلاص الالومنا كما في شكل رقم (٤) .

ومن المقارنات السابقة بين البوكسايت والكاولين نجد أن عناصر الانفاق المختلفة بما في ذلك الطاقة تختلف من بلد الى آخر وقد عملت بعض الدراسات المقارنة من قبل شركات الالومنيوم الكبرى وبعض المؤسسات البحثية ، وقد تبين من الدراسة المقارنة التى قام بها زيفنبالق وهاك سنة ١٩٨٣ على الكاولين عند استعمال الأحماض المختلفة أن التكاليف والمشاكل التقنية يمكن ترتيبها كما يلى: (٦)

يد ن أ٣ > يد٢ كب أ٤ > يد٢ كب أ٣ > يد كل

وكذلك أيضا تم مقارنة عملية باير للبوكسايت مع الكاولين باستخدام حامض الهيدروكلوريك وحامض الكبرتيك ودونت نتائجها بالشكل رقم (٥) . ومن منشورات مكتب معلومات المناجم بالولايات المتحدة الامريكية تحت رقم ٨٦٤٨/١٩٧٤ (٧) وجد أن الطاقة الحرارية المستخدمة في استخلاص الالومنيوم من الكاولين باستخدام حامض الهيدروكلوريك وحامض النيتريك يمكن تلخيصها كالآتى :-

١- الطاقة الحرارية المطلوبة لاستخراج طن واحد الومنا من كاولين جورجيا = ٠٠٠ر١٠٠ر٤٩ (ب . ت . يو) وذلك باستخدام حامض النيتريك ، يستخدم منها حوالى ٠٠٠ر٠٠٠ر٥ (ب . ت . يو) على الطن الواحد الومنا في عملية

الحرق المباشر للطين والباقي في عمليات الاستخلاص الأخرى .

٢- الطاقة الحرارية المطلوبة لاستخراج طن واحد الومنا من كاولين جورجيا باستخدام حامض الهيدروكلوريك = ٣٧٫٨٠٠٫٠٠٠ (ب . ت . يو) ، يستخدم منها حوالي ١٢٫٠٠٠٫٠٠٠ (ب . ت . يو) في عملية الحرق المباشر والباقي في العمليات الأخرى .

أما الطاقة الكهربائية بالنسبة لطن واحد من الألومنا فهي : ١٦٣ ك .و.ساعة وذلك باستعمال حامض النيتريك و ١٣٤ ك .و. ساعة عند استعمال حامض الهيدروكلوريك ونظرا لحداثة هذه العملية الصناعية فانه يتحتم بذل المزيد من الجهد والدراسة سواء في اطار معملي أو على شكل مصانع بحثية مصغرة من أجل ايجاد أنجع الوسائل في سبيل التقليل من الانفاق وبالتالي التقليل من الطاقة المستهلكه في انتاج الألومنا من خام الكاولين حتى تكون في مستوى عملية باير للبوكسايت .وبالاضافة الى الغاز الذي يعتبر أهم مصادر الطاقة سواء للكلسنة أو الاستخلاص فانه بالامكان استعمال البترول والفحم كمصادر للطاقة في استخراج الالومنا .

٤- المواد المساعدة :-

لكل قطر أسبابه ومبرراته التي يقدمها لانشاء مصهر الالومنا لديه ،وربما يكون الدافع الأساسي لذلك توفير عامل او اكثر من العوامل التي تساعد على اقامة مثل هذا المشروع .

فربما يكون هذا الدافع هو توفير الطاقة أو المادة الأولية ، مادة البوكسايت أو كليهما معا ، واذا ما توفرت مع هذين العاملين عوامل أخرى (مثل رأس المال ، السوق) فان فرص نجاح وتحقيق اقامة هذا المشروع تكون وافية .

وفي ضوء ذلك نجد أن العوامل الرئيسية الهامة لاقامة هذه الصناعة بالاضافة الى الخام تتلخص فيما يلي :

٤-١ الطاقة :- تعتبر الطاقة أول وأهم العوامل التي تتحكم في هذه الصناعة اذ يحتاج صهر الالومنيوم الى توفير مصدر ثابت غير منقطع من الطاقة مما يؤمن استمرارية التغذية . كما تتميز الجماهيرية ومعظم الدول العربية المنتجة للنفط بتوفر كمية هائلة من الغاز المصاحب والغاز الطبيعي ، وجانب كبير من هذه الطاقة يتم حرقه ، ويعتبر انتاج الالومنا مصدر مهم للاستفادة من هذا الغاز في توليد الطاقة الكهربائية .

٤-٢ القطران : تستخدم هذه المادة في تحضير الاقطاب الكربونية ويمكن الحصول عليها من تكرير منتجات النفط .

٤-٣ العمالة : يحتاج مشروع متكامل للالومنا الى عدد من العاملين ممن ذوى الخبرة والمهارة ، ويستخدم مصنع الالومنا حوالي ١٥٠٠ شخص .

٤-٤ الفحم البترولي : تعتبر الجماهيرية مصدر طبيعي وجيد للفحم البترولي ويقدر انتاج طن واحد من الالومنا الخام بحوالى نصف طن من الفحم البترولى .

٤-٥ رأس المال : اهم عنصر يتطلبه أى مشروع هو توفير رأس المال اللازم لشراء المعدات واقامة المنشات .

٥- الاستنتاج :

٥-١ بالنظر الى الأهمية الاستراتيجية لهذه الصناعة فان التفكير فى اقامتها على الخامات المحلية يعتبر من الأمور الهامة جدا لأى بلد .

٥-٢ من الدراسة السابقة بالنسبة الى استخلاص الالومنا من خام كاولين سبها فان النتائج تشير الى امكانية الحصول على حوالى ٩٨ ٪ الومنا الأمر الذى يؤكد احتمالية قيام صناعة الومنا معتمدة على خامات وطنية آخذه فى الاعتبار امكانية الاستفاده من النواتج الثانوية لمصنع أبو كماش وتزويد بعض النواتج الثانوية من هذه الصناعة لبعض المصانع الأخرى .

٥-٣ نظرا لحداثة صناعة الالومنا من الكاولين يجب أن تولى قدرا متزايدا من الدراسة والتشجيع على أن تشمل هذه الدراسة الجوانب الفنية والاقتصادية معا وذلك فى سبيل التقليل من الطاقة بما يكفل منافستها عملية شـراء الومنا مصنعة من البوكسايت .

٥-٤ وجود الغاز الطبيعى فى الجماهيرية ودخول الجزائر كطرف شان فى هذه الصناعة من الممكن أن يوفر السوق الجيدة للانتاج فى دول المغرب العربى التى لم يسبق لها استيطان هذه الصناعة من قبل .

٥-٥ بيع الغاز الوطنى فى صورة الومنا مصنع من العوامل الهامة جدا فى مضاعفة سعره وبالتالى دعم الاقتصاد الوطنى .

٥-٦ استعمال الفلورايد أيون للتفاعل من الممكن أن يخفض الطاقة الحرارية المطلوبة لانتاج طن واحد من الألومنا من الكاولين الى ٢٥٫٨٠٠٫٠٠٠ ب ت يو وذلك بالاستغناء عن عملية الكلسنة حتى تنافس عملية باير للبوكسايت .

المراجــع

١- افاق تطوير صناعات المواد الاولية لصناعة الالومنيوم فى الدول العربية ، محمد سعيد جابر ، المؤتمر العربى الدولى الثالث للألمنيوم ، اكتوبر١٩٨٧.

٢- واقع وافاق تطوير صناعة الالومنيوم فى الوطن العربى ، أحمد عباس ، المؤتمر الثالث للألمنيوم ، اكتوبر ١٩٨٧ .

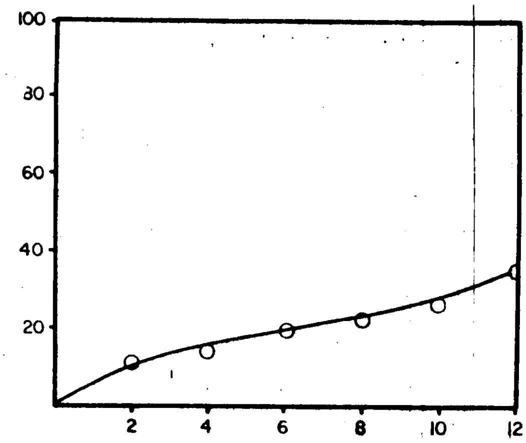
٣- ملامح التغيير في صناعة الالمنيوم ، وجهة نظر اقتصادية ، جيمس اف .كينج ، المؤتمر العربى الدولى الثالث للألمنيوم ، اكتوبر ١٩٨٧ .

٤- تسعير الغاز الطبيعى وصناعة الالمنيوم فى ليبيا ، د. شكرى غانم ، الندوة الليبية / الايطالية المشتركة حول قضايا الطاقة ، اكتوبر ١٩٨٧ ، ص ٨ .

٥- استخلاص الالومنيوم من الكاولين ، سليمان قجم ، المؤتمر الأول للصناعة ابريل ١٩٨٨ .

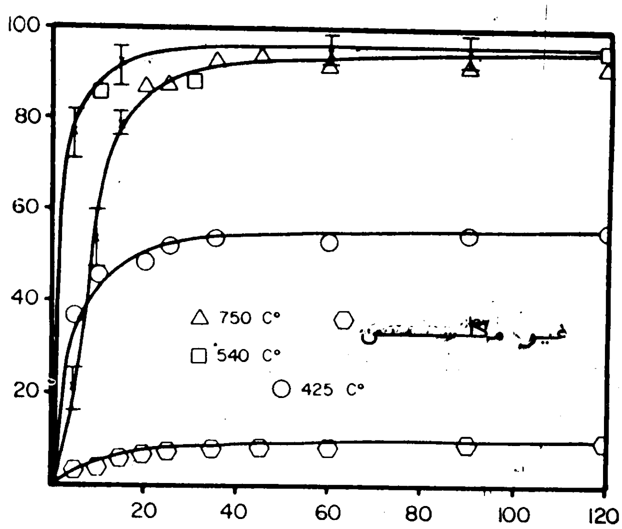
٦- ذيفنبالق و س. وهاك . ج ، " دراسة استخلاص الالومنا من الكاولين باستعمال حامض الهيدروكلوريك وحامض الكبرتيك " الفلزات الخفيفة ، ص ١١١٩ - ١١٤٣ ، ١٩٨٣ .

٧- منشورات مكتب معلومات المناجم بالولايات المتحدة الامريكية ، رقم ١٩٧٤/٨٦٤٨ .



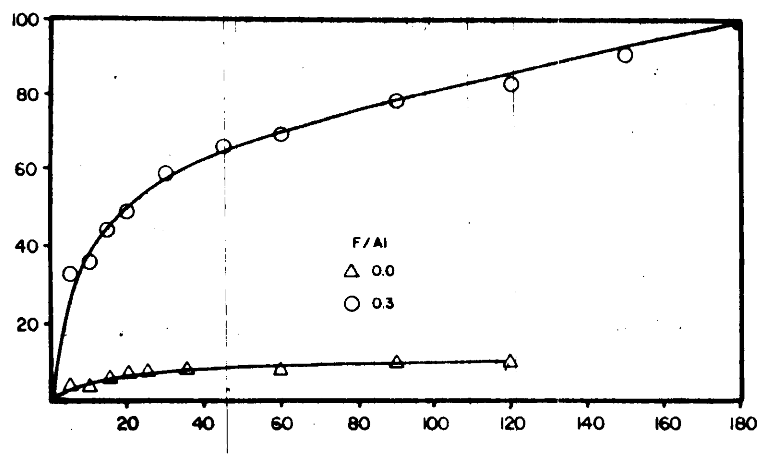
شكل رقم (١)

استخلاص الالومنيوم من طين الكاولين الغير مكلسن باستعمال حامض الهيدروكلوريك عند درجة حرارة ٩٥ م



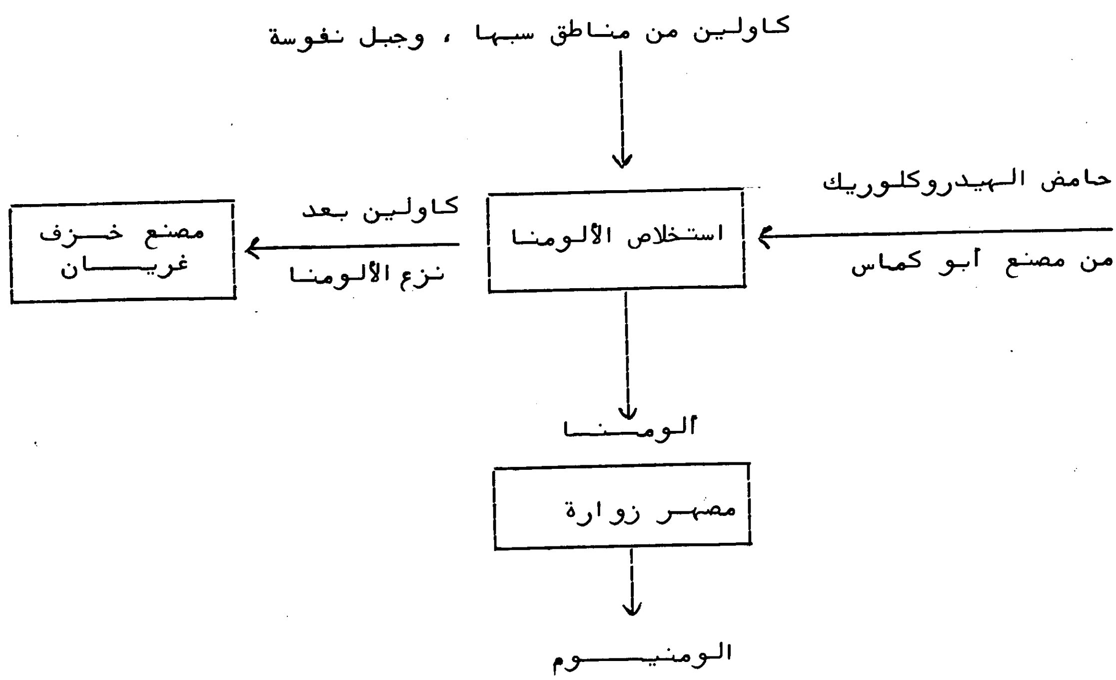
شكل رقم (٢)

استخلاص الالومنيوم من طين الكاولين المكلسن عند درجات الحرارة المختلفة باستعمال حامض الهيدروكلوريك تحت درجة جرارة ٩٥ م



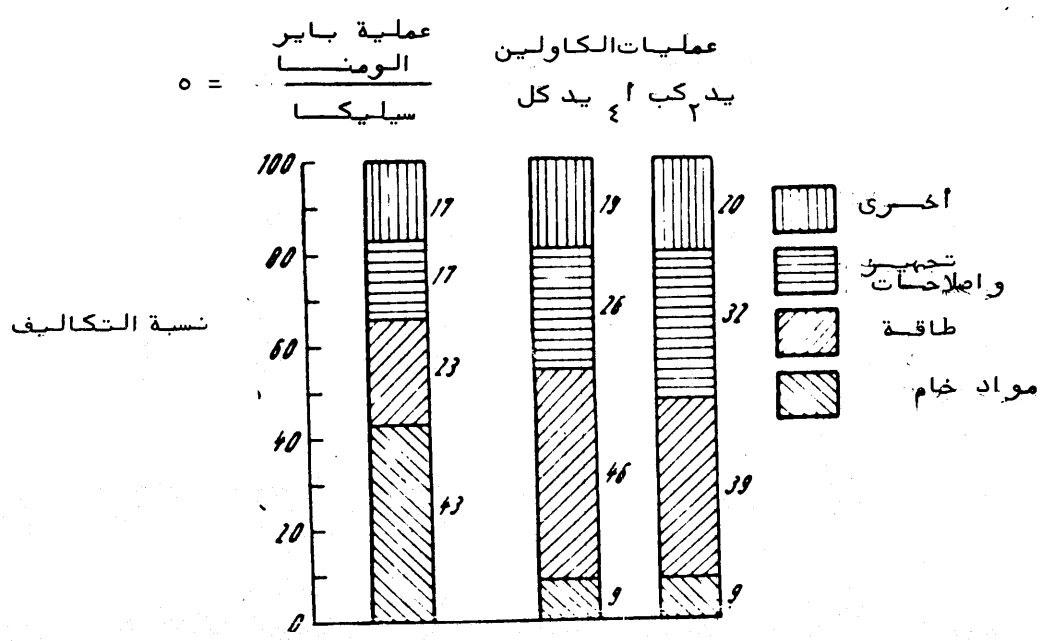
شكل رقم (٣)

استخلاص الالومنيوم من طين الكاولين الغير مكلسن باضافة الفلورايد أيون واستعمال حامض الهيدروكلوريك تحت درجة حرارة ٩٥ م



شكل رقم (٤)

يبين علاقة مصنع الالومنيوم بالمصانع المحلية الاخرى



شكل رقم (٥)

تكاليف استخلاص الالومنيوم من العمليات المختلفة (٦)

IMPROVED FUEL ECONOMY IN A SPARK IGNITION ENGINE THROUGH BETTER MIXTURE PREPARATION

S.Shah, J.P.Subrahmanyam and M.K.Gajendra Babu

Department of Mechanical Engineering
Indian Institute of Technology
New Delhi 110 016 INDIA

ABSTRACT

Spark ignition engines are widely used in passenger cars as a prime mover. Due to their growing numbers, they consume a large quantity of gasoline whose reserves may decline to an alarming level if their consumption rate is not reduced. Among the several methods that may be contemplated to achieve this objective, improved mixture formation in the manifolds can be considered as a viable technique.

Hence, in this paper, experimantal investigations relating to the improved mixture preparationin the inlet manifold of a spark ignition engine are described. This improvement is achieved by enhancing the turbulence levels with the help of delta-shaped wing generators joined in the form of a cone with an apex angle of 50 degrees. Two such generators comprising 50 and 75 per cent blockage ratios are placed ahead of the carburettor in the inlet manifold of an instrumented four stroke cycle single cylinder spark ignition engine. Experiments have been conducted over a wide range of operating conditions encompassing broad changes in engine speed, fuel air equivalence ratio and spark timing to study their effects on engine performance.

The present studies have shown that enhanced turbulence levels in the inlet manifold improves the engine performance under lean operation due to a better mixture formation. It is envisaged that the present investigations could pave the way to fuel economy.

1. INTRODUCTION

Automobiles have always been a convenient and fast moving personalised mode of transport. Even in a developing country, like India, the automobile is no longer a status symbol. The number of cars on the road is increasing day by day.

The most common and widely used power plant for these passenger cars in India is the carbureted spark ignition engine. This is because the spark ignition engine is relatively lighter in weight, operates at lower temperatures and pressures and is more flexible in operation when compared

with any other competitive power plant, notably the compression ignition engine.

One of the major drawbacks of the carbureted spark ignition engine is that it employs a mixture of fuel(gasoline or petrol) and air as its working medium. While on one hand the very nature of the combustion process (commencing with the ignition by means of a spark and ending with the flame propagation across the combustion chamber consuming the charge) necessitates the maintenance of a homogeneous air-fuel mixture within a small range; on the other hand it is difficult to obtain and manitain a truly homogeneous mixture.

The homogeneity of the dispersion of a volatile fuel, such as petrol, in air and the physical state of the fuel-air mixture is described by the term "mixture quality". As the term indicates, a better mixture quality is expected to improve combustion, performance and emission characteristics. It affects the ability of an engine to run on lean mixtures without misfire.

A number of methods have been proposed to improve the mixture quality* of a spark ignition engine. One method is by vaporisation of the fuel[1-3] A normal carburettor produces a wet and non-homogeneous mixture and the fuel is unevenly distributed between the inlet manifold branches. In a multicylinder engine some cylinders would receive leaner mixtures than othersand this would lead to misfiring in those lean-mixture-cylinders.

Complete vaporisation of gasoline in air occurs at fairly low temperatures (around 40 to 60 degrees Celsius at atmospheric pressure for a stoichiometric mixture). However, when the fuel evaporates it cools the air to such an extent that further evaporation may not be possible resulting in liquid droplets being carried along with the vaporised mixture. To avoid this problem, Hughes and Goulburn provided a heating system in the intake. The source of heat was the coolant. They were able to reduce the specific fuel consumption and the engine required lower minimum spark advance for best torque. The drawback was that the engine produced lower power at normal fuel-air ratio operation because of reduced air intake. Since the specific volume of fuel vapour is higher than that of fuel liquid, it displaces air , resulting in lower charge intake and hence reducing power. Another problem was to obtain heat at the time of starting the engine from cold.

Beale and Hodgetts[4] tried inlet valve throttling as a means of improving the mixing of air and fuel at low speeds. Their argument was that the significant change with load and speed is the mixture velocity or more likely the kinetic energy of the flow through the valve aperture and, subsequently, the mixing and turbulence of thr fuel, air and exhaust residuals in the combustion chamber. Under idling, the density and velocity of the mixture are low and mixing and turbulence of the cylinder contents which include a high mass fraction of residuals is inadequate for good combustion. By providing inlet valve throttling for increasing the velocity of flow at low lifts they were able to obtain high turbulence at part load. With this arrangement they were able to run the engine on lean mixtures at part load and obtain lower emissions.

Lucas et al[5] suggested that for overcoming the problems associated with lean mixture running, it was necessary to enhance the turbulence levels in the combustion chamber. This may be achieved by either increased intake-

*Numbers in square brackets indicate references at the end of the paper

generated turbulence or by producing turbulence inside the cylinder by means of squish. They studied the effects of squish on combustion and performance characteristics and obtained improvements in both.

Improvements in mixture preparation by using turbulence generators in the intake were obtained by Quader[6] with baffles, Tanuma et al[7] with a special intake-valve insert and by Lindsay et al[8] with a mixture generator. Lawton et al [9] used a delta wing type turbulence generator in a rotary piston engine intake to generate high turbulence intensities. Such a type of turbulence generator was tried by Lucas et al[10] in a spark ignition (reciprocating) engine. An earlier study[11] involved the use of a set of blades (swirlers) to generate turbulence in the engine intake.

In all these studies it was seen that the engine could be run leaner and the fuel consumption was reduced.

In the present analysis, the effect of improving the mixture quality by means of intake generated turbulence on the performance characteristics of a single cylinder four stroke spark ignition engine was studied. Turbulence was generated by means of a cone-shaped device made from four delta-shaped wings joined together. Experimental invesigations were carried out over a wide range of operating conditions encompassing broad changes in engine speed, fuel air equivalence ratio and spark timing.

2. EXPERIMENTAL SETUP AND TECHNIQUE

The engine and its associated instrumentation and the turbulence generator are described in this section.

2.1 The Engine

The single cylinder four stroke Ricardo E6 Variable Compression Ratio Spark Ignition Engine was used for the present experimental study. A fixed compression ratio of 7:1 was employed. The engine has a compact, disc-shaped combustion chamber with a flat cylinder head and piston top and very little squish effect. The spark plug is located off-centre. Fuel flow was measured by timing a fixed quantity of fuel from calibrated burettes. The air flow rate was measured with the help of a calibrated Alcock Viscous Air Flow Meter in conjunction with an inclined manometer. Details of the engine are given in the appendix.

The engine is coupled to a Lawrence Scott NS type Swinging Field A.C. Dynamometer with motoring facilities.

2.2 The Turbulence Generator

A conically shaped device was fabricated from four delta-shaped wings joined at the apex. The apex angle was chosen to be 50 degrees. The blockage ratio, which is a measure of the area of flow which is blocked, is defined, referring to Fig. 1 as

$$\text{Blockage Ratio} = (A_1+A_2+A_3+A_4)/A$$

where A is the total area of flow and A_1, A_2 etc. are the projected areas of the delta wings in the plan view.

In the present study, two blockage ratios were employed, namely, 50 and

75 per cent. The turbulence generator was placed in the inlet pipe ahead of the carburetter with its apex pointing towards the carburetter in order to increase the angle of attack. Vortex turbulence is generated by first moving radially outwards and then rolling off the wing edges[9].

3. TEST MATRIX

For the experimental work the following test matrix was employed. The values underlined indicate baseline conditions.

Speed rev/min	1000	1200	1400	1600	1800	2000	2400
Spark Timing Deg btdc	20	25	30	35	40		
Equivalence Ratio	0.8	0.9	1.0	1.1			
Blockage Ratio	0.0	0.5	0.75				

4. RESULTS AND DISCUSSION

Performance tests were carried out on a single cylinder four stroke cycle spark ignition engine without a turbulence generator and with 50 and 75 per cent blockage ratio turbulence generators.

4.1 Baseline Conditions

Figure 2 gives a plot of brake horsepower with engine speed for the base engine and with the turbulence generators having 50 and 75 per cent blockage ratio.

The graph shows that at low speeds, if the turbulence level is high, characterised by a high blockage ratio, the brake horsepower is higher than that for the base engine. This trend gets reversed at higher speeds. It is also seen that at the higher blockage ratio, the speed at which power improvement is maximum is lower than the speed for the lower blockage ratio. It is observed that for 50 per cent blockage ratio, the best power speed is 1800 rev/min while for the 75 per cent case it is 1200 rev/min.

4.2 Effect of Equivalence Ratio

Plots were made for brake horsepower with speed at three other equivalence ratios, namely, 0.8, 0.9 and 1.1. These are depicted in Figs. 3 to 5.. The trends are similar to that obtained for the stoichiometric air-fuel mixture. While there is a significant improvement for the lean mixtures there is hardly any improvement in the rich mixture case.

Figures 6 and 7 give plots of power with equivalence ratio for the two blockage ratios tested. It is seen that for the lean mixture the improvement in power is the highest. A cross-plot of power improvement with equivalence ratio shows this more clearly in Fig. 8. There is a considerable drop in improvement in power when moving from lean mixtures to stoichiometric. Beyond stoichiometric mixture, the improvement is barely discernable.

4.3 Fuel Consumption

Figures 9 and 10 give plots of the "Fuel Consumption Loop" for the baseline case and the case with the turbulence generators. It is seen that there is a significant decrease in the brake specific fuel consumption with the turbulence generator.

Plots of brake specific fuel consumption with equivalence ratio are given in Figs 11 and 12. They show that fuel consumption is lower at lean mixtures with turbulence generated in the intake. There is a greater improvement with the 75 per cent blockage ratio turbulence generator.

4.4 Discussion

It has been reported in the literature that increased intake-generated turbulence improves the operating characteristics of a spark ignition engine running on lean mixtures[5-7]. These researchers have shown that swirl would affect the combustion characteristics. Lawton et al[9] who used delta-wing shaped turbulence generators in a rotary piston engine, however, believe that though the turbulence intensity in excess of 20 per cent was generated near the device, this quickly decayed and was unlikely to be significant during combustion. But apparently because the uniformity of mixture preparation, that is, there was an improvement in mixture quality, consistent ignition at lean air-fuel mixtures was achieved. Improvements in rich air-fuel mixtures were not observed.

In the present analysis the improvement in power and reduction in fuel consumption may be attributed to the improvement in mixture preparation although the increased turbulence does contribute to higher flame speeds[12].

5. CONCLUSIONS

From the present analysis, the following conclusions may be drawn:

1. The conical turbulence generator made from four delta shaped wings is an inexpensive method for generating turbulence in the intake of a spark ignition engine. The device is relatively simple and easy to fabricate and install.
2. The device improves mixture quality by making it more homogeneous. Power is increased and fuel consumption is reduced.
3. The lower the blockage ratio, the higher the speed at which it will produce best results.
4. Since the system works more effectively at lean mixtures, it would be expected to extend the lean mixture limit of the engine.

REFERENCES

1. Hughes, D.W. and Goulburn, J.R.,"Fuel Vaporisation-Economy with Reduced Exhaust Emissions", Proceedings of I.Mech.E., vol. 190, 1976, p 1-11.
2. Hughes, D.W. and Goulburn, J.R.,"Economy with Reduced Exhaust Emissions-A Simple Technique", S.A.E. Paper No. 760140.
3. Goulburn, J.R. and Hughes, D.W.,"The Interaction of Automotive-Engine Efficiency and Exhaust Pollution", Energy Research, vol. 1, 1977, p 31-46.
4. Beale, N.R. and Hodgetts, D.,"Inlet Valve Throttling and the Effects of Mixture Preparation and Turbulence on the Exhaust Gas Emissions of a Spark Ignition Engine", Proceedings of I.Mech.E., vol. 190, 1976, p 13-21.
5. Lucas, G.G., Brunt, M.F. and Anton, R.,"The Effect of Squish on Charge Turbulence and Flame Propagation in a Spark Ignition Engine", I.Mech.E. Conference Publication, Paper No. C87/79, 1979, p 1-18.

6. Quader, A.A.,"Lean Combustion and the Misfire Limit in Spark Ignition Engines", Transactions of S.A.E., vol. 83, 1974, p 3274-3296.

7. Tanuma, T., Sasaki, K., Kaneko, T. and Kawasaki. H.,"Ignition, Combustion and Exhaust Emission of Lean Mixtures in Automotive Spark Ignition Engines", Transactions of S.A.E., vol. 80, 1971, p 663-673A.

8. Lindsay, R., Thomas, A., Woodsman, J.A. and Zeschman, E.G.,"Influence of Homogeneous Charge on the Exhaust Emissions of Hydrocarbons, Carbon Monoxide and Nitric Oxide from a Multicylinder Engine", S.A.E. Paper No. 710588.

9. Lawton, B., Elmore, K.G. and Render, M.E.J.,"Performance of a Small Scale Turbulence Generator in a Rotary Piston Engine," I.Mech.E. Conference Publication, Paper No. C93/79, 1979, p 71-80.

10. Lucas, G.G., Brunt, M. and Petrovic, S.,"Lean Mixture Running of the Spark Ignition Engine by the Generation of a Vortex System Within the Intake", S.A.E. Paper No. 780964.

11. Kochhar, R. and Dabir, R.,"Some Studies of Turbulence in a Four Stroke Spark Ignition Engine", B.Tech. Dissertation, Mech. Eng. Dept., I.I.T. New Delhi, India, May 1986.

12. Shah, S.,"Study of Combustion Duration and Performance of a Four Stroke Spark Ignition Engine with a Turbulence Generator in the Inlet Pipe", M.Tech. Dissertation, Mech. Eng. Dept., I.I.T. New Delhi, India, December 1986.

APPENDIX

Engine Specifications

Type	Ricardo E6/T Variable Compression Ratio
Bore	76.2 mm
Stroke	111.125 mm
Ignition	Spark, Magneto Type
Coolong Water System	Closed Circuit
Normal Speed Range	1000 to 3000 rev/min
Range of Ignition Setting	20 to 60 degrees before top dead centre (btdc)
Fuel used	Commercial Gasoline

ACKNOWLEDGEMENTS

The authors wish to acknowledge with thanks the help rendered by the staff of the Internal Combustion Engines Laboratory of the Mechanical Engineering Laboratory of the Indian Institute of Technology, New Delhi, India during the course of this investigation.

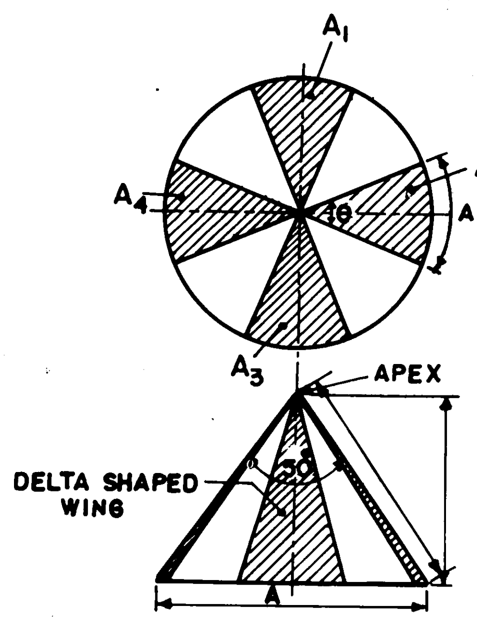


FIG. 1 ELEVATION AND PLAN OF TURBULENCE GENERATOR SYSTEM

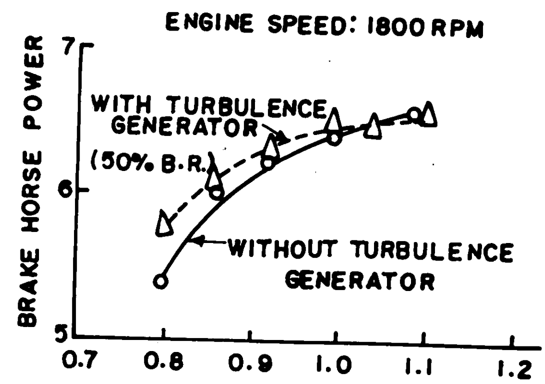
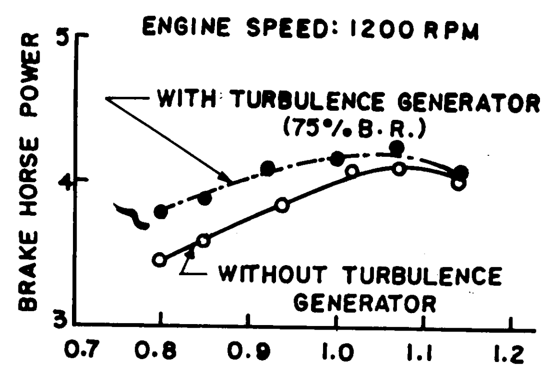


FIG. 3



EFFECT OF EQUIVALENCE RATIO ON BRAKE HORSE POWER

FIG. 4

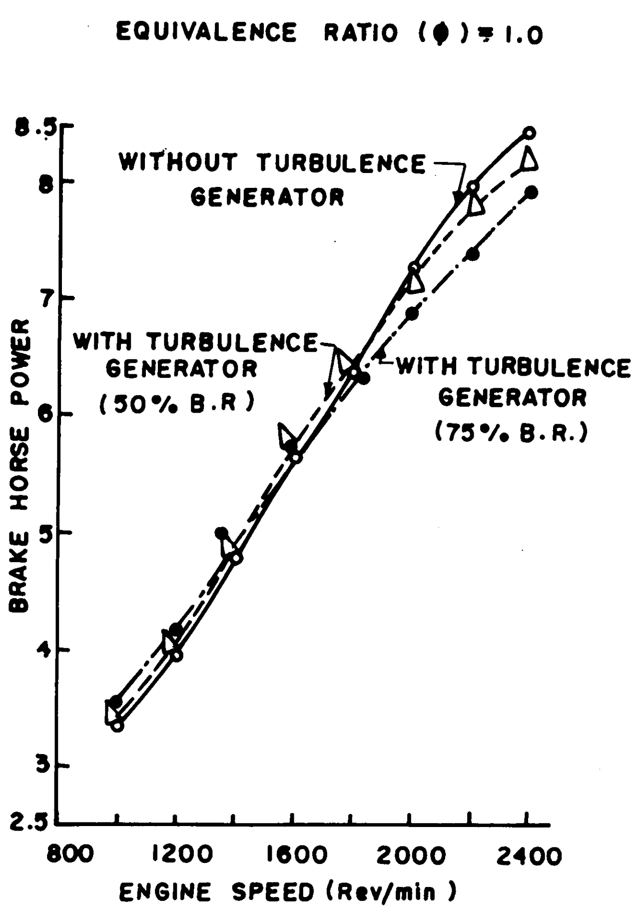


FIG. 2 EFFECT OF SPEED ON BHP AT ϕ=1.0 WITHOUT & WITH TURBULENCE GENERATOR (50% & 75% B.R.)

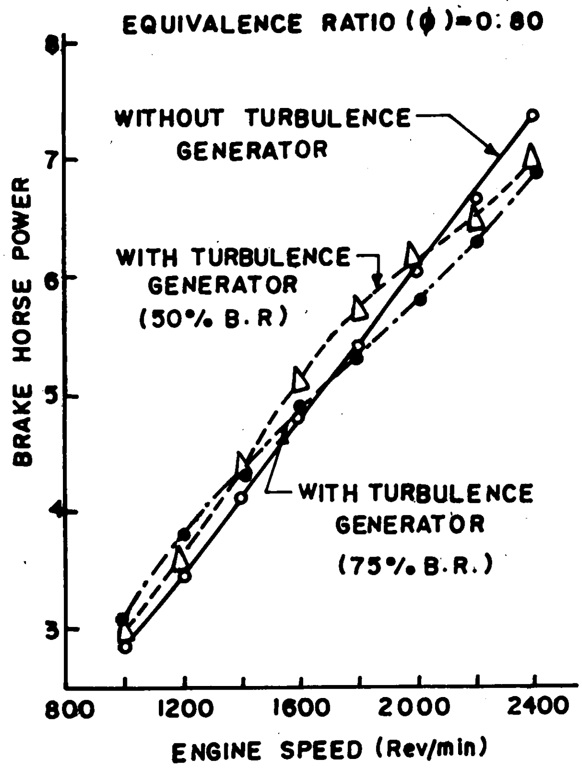


FIG.5 EFFECT OF SPEED ON BHP AT ϕ=0.8 WITHOUT & WITH TURBULENCE GENERATOR (50% & 75% B.R.)

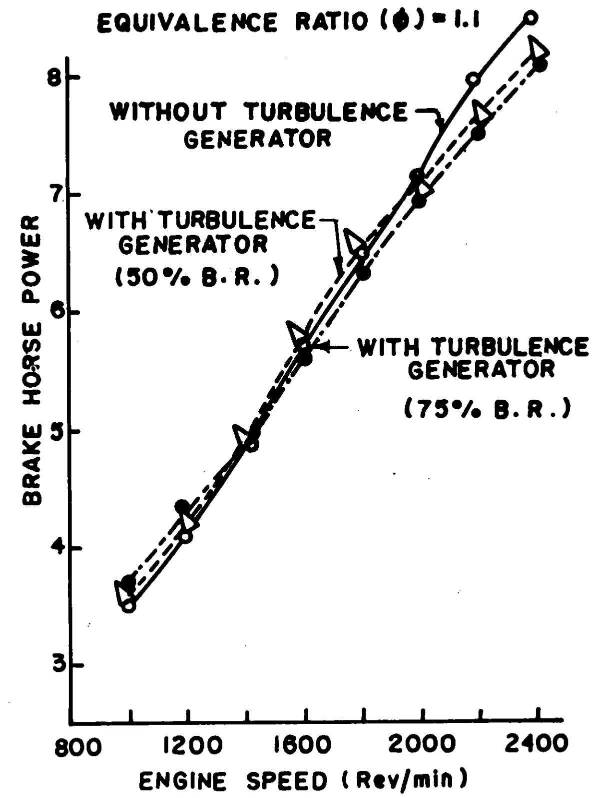


FIG.7 EFFECT OF SPEED ON BHP AT ϕ 1.1 WITHOUT & WITH TURBULENCE GENERATOR (50% & 75% B.R.)

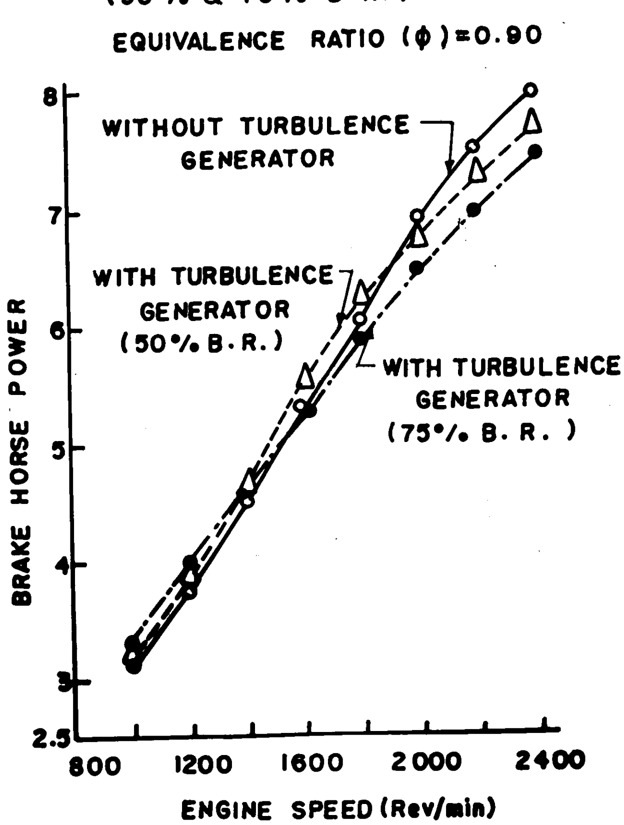


FIG.6 EFFECT OF SPEED ON BHP AT ϕ 0.9 WITHOUT & WITH TURBULENCE GENERATOR (50% & 75% B.R.)

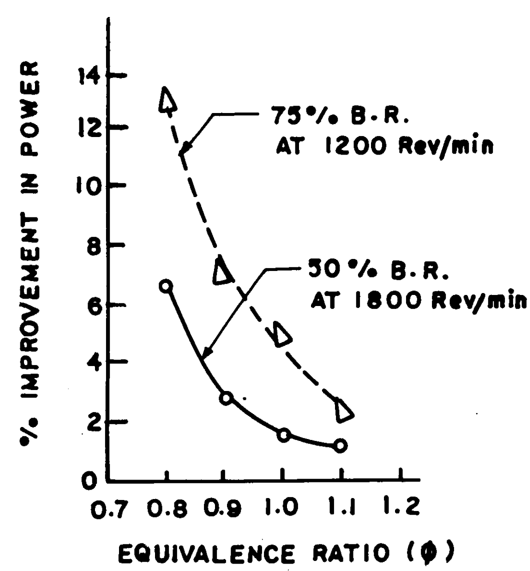


FIG. 8 VARIATION OF POWER IMPROVEMENT WITH EQUIVALENCE RATIO

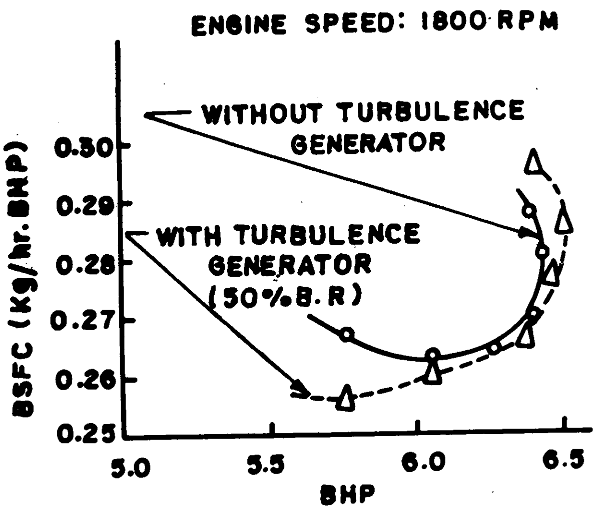


FIG. 9 REDUCED BSFC WITH TURBULENCE GENERATOR (50% B.R.)

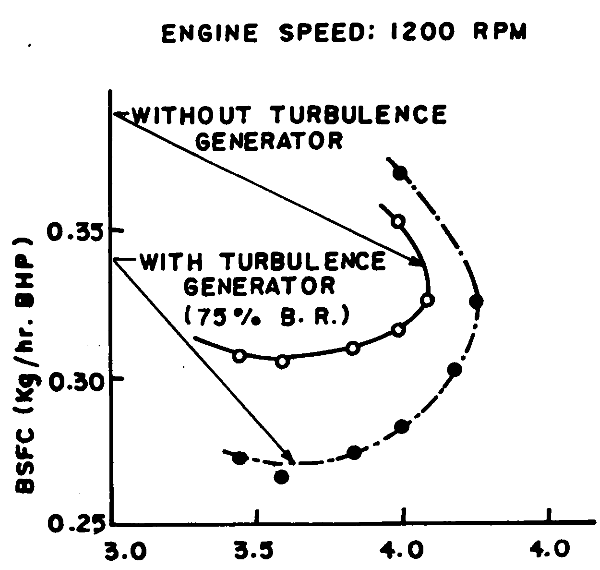


FIG. 10 REDUCED BSFC WITH TURBULENCE GENERATOR (75% B.R.)

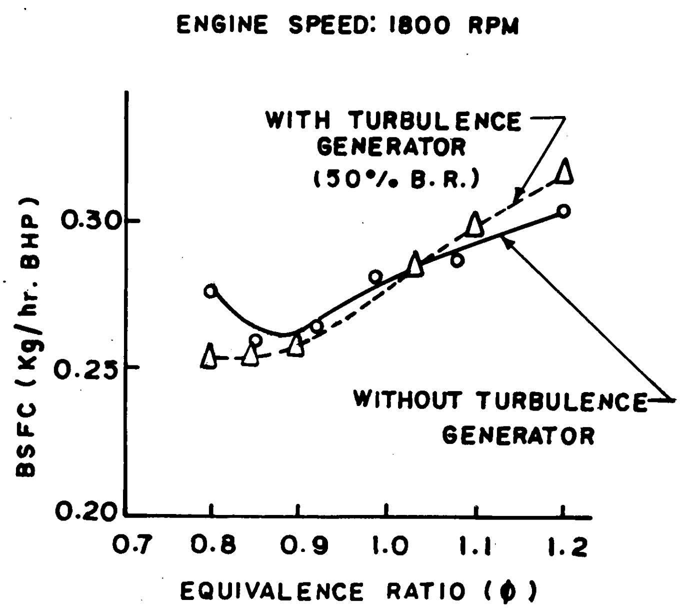


FIG. 11 IMPROVED BSFC IN LEAN REGION WITH TURBULENCE GENERATOR (50 % B.R.)

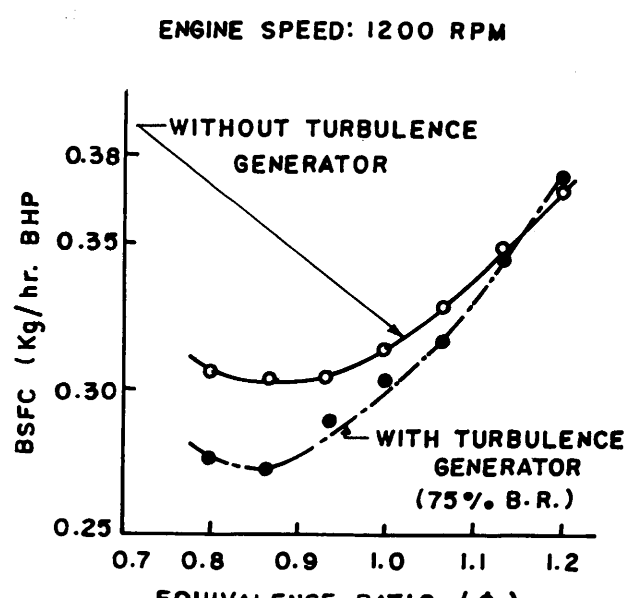


FIG. 12 IMPROVED BSFC IN LEAN REGION WITH TURBULENCE GENERATOR (75% B.R.)

ENERGY CONSUMPTION : A NEW DIMENSION IN TRANSPORTATION PLANNING & ENGINEERING

S. P. Bindra

Urban Planning Research Unit
Garyounis University
Benghazi, Libya

ABSTRACT:

The paper presents an overview of the global state of the art on energy consumption by transportation system. Innovations in energy forms and their possible applications in transportation are also presented. An attempt is made to develop a comparative energy efficiency measures for different transportation modes with a view to present an advance integrated transportation.plan with special reference to Libyan conditions. Modern trends in transportation planning and engineering along with issues like energy conservation in transportation planning are the main features of the paper.

1. INTRODUCTION:

Transportation is one of the major users of energy. As per one of the estimate (1) Transportation systems consume about one quarter of all energy used, with highway vehicles accounting for 20%, aircraft for 2%, railroads (including rail transit), ships and pipelines for 1% each. Almost all of this energy is in the form of petroleum fuels, a small amount of natural gas is used primarily by the pipeline systems. The amount of electricity and coal used is insignificant.

Energy crisis is a global problem which has two equally alarming facts: (i) the rapid rate at which known reserves of conventional fuels are getting depleted, and (ii) the escalating cost of fuel. At the present rate of consumption of petroleum resources, the known reserves and those that can be explored and exploited in future would be exhausted by the middle of the next century.

The economic growth as well as industrial activity is dependent upon transport - both public and personal. Even if Libya discovers a substantial quantity of its own oil, both onshore and offshore, conservation of gasoline will still be

be necessary as the rate of consumption will also continue to grow with increased industrialization and urbanization. Thus energy plays a pivotal place in the national economy and daily life. The primary goal of future energy policies will have to be to utilize the nation's sizable indigenous resources and develop renewable sources of energy.

Transportation planners, recognising that transportation is one of the major users of energy, must make efforts in minimizing transportation energy requirements while maintaining a desired level of mobility. The transportation factors affecting fuel consumption may be categorised into two basic categories, the demand for transportation service and the fuel efficiency by which such service can be provided. The demand for transportation services has increased manifolds. That increase has been attributed to the general population growth, the movement to the suburbs, the growth in economic activity, and the rise in personal income, all of which have been responsible for the increase in the number and length of vehicle trips.

2. AN APPRAISAL OF ALTERNATIVE SOURCE OF ENERGY FOR TRANSPORTATION:

Many attempts have been made in recent past on various alternate fuels to replace or supplement gasoline and diesel. Adoption of any alternate fuel has to be carefully judged on the basis of: (i) performance, (ii) fuel economy, (iii) reduce air pollution, and (iv) minimum changes in engine design. The present status of research in this field is analyzed in this paper.

Major alternate fuels for engines may be classified as follows:

1. Fuels that can be produced from vegetation such as alcohols (both ethyl and methyl).
2. Fuels that can be produced from coal such as methanol, liquified coal oil and benzol.
3. Fuels that can be produced from municipal wastes such as bio-gas, or gobar gas and sewage gas.
4. Hydrogen.

2.1 Ethanol (Ethyl Alcohol):

A clean burning synthetic fuel which can be manufactured from a wide range of raw materials such as vegetable matter, growing crops, farm waste, tropical grasses, waste organic products, molassess, etc. As long as energy from the sun is available, plants will perform their synthesis for starch from the abundant carbon dioxide and water. Sugarcane is one of the most efficient converters of solar energy. Vegetable sugars, which are carbohydrates, can be fermented to yield various chemical products including alcohol as expressed by the

Gay-Lussac relation:

$$C_6H_{12}O_6 \qquad 2C_2H_5OH + 2CO_2$$

2.2 Methanol:

It is manufactured from a host of organic materials including lignite, wood, coal, natural gas and indirectly from municipal and farm wastes. Methanol from coal can provide an indigenous substitute for oil. In countries which have vast reserves of coal but meagre oil deposits conversion of coal to methanol is simpler and cheaper as compared to its liquefaction into gasoline.

2.3 Uses of Ethanol and Methanol in IC Engines:

Many studies on both petrol (gasoline) and diesel engines using either of these alcohols in engines show that (i) Engines designed to run on gasoline can be run directly on ethanol or methanol with only minor modifications dealing mainly with the carburettor and intake manifold. If, on the other hand, a mixture of gasoline with alcohol is used, these modifications are further simplified or altogether eliminated so that the existing engines can be run with some readjustment to the carburettor. Use of an optimum blend can increase power output, slight improvement in efficiency and reduced concentration of major pollutants.

Diesel engines can be run as dual fuel engines with alcohol supplied to the engine by means of either a carburettor or by manifold injection. The improvements are drastic reduction in smoke and fuel consumption and smooth engine running. Up to 70% of the fuel required at full load can be supplied by alcohol. Blends of ethanol in gasoline are in commercial use in Brazil and Cuba.

2.4 Benzol:

Benzol is byproduct from coal carbonized for gasification or preparation of metallurgical coke. While some quantities of Benzol are recoverable from the light oil coal tar, almost all benzol recovered is obtained by scrubbing coke oven gases.

Benzol can be blended with gasoline to stretch its availability without any major modification in engine design or transport equipment. It is not only an excellent motor fuel when used alone, chiefly due to its anti-smoke property but is able to boost the octane rating of other fuels with which it is blended. Alcohol and benzol can be mixed without problem of phase separation. Benzol is completely miscible with gasoline in all proportions. Experimental investigations have shown that there is an all round increase in engine power output. The optimum blend also shows economy in fuel consumption.

2.5 Hydrogen:

Hydrogen appears to be an ideal fuel for future automobile engines. It is the cleanest possible fuel in use. It can be produced from water by using nuclear or solar energy and it can be made available in potentially unlimited quantities in the long run. However, at present, hydrogen cannot be produced at reasonable cost with the present methods of production. Other practical difficulties are handling, storage and safety.

The technical feasibility of using hydrogen for IC engines has been more or less firmly established. A number of automobiles have successfully run on hydrogen. In Australia, some of the petrol engines have been adapted to run on hydrogen. However further research is needed to develop expertise in the technology of hydrogen production, transmission, storage and utilization before it can be commercially viable.

2.6 Bio Gas:

Bio-gas can be used for both SI and CI engines. Its application to small stationary engines in rural areas is getting popular.

3. NATIONAL PLANNING AND TRANSPORTATION SCNERIO IN LIBYA:

Libya is the fourth largest state in Africa with a total land area of approximately 1.76 million square kilometers, with a Mediterranean coast-line of about 1,900 Km. In the late 1960's the total population was approximately 1.869 million, increasing to 2.970 million by 1976. In 1980, the population attained a 3.3 million level, and this is projected to approach 6.2 million by the end of the century. With such vast land territory, the country is very sparsely populated. In the 1960's population density was approximately one person per km^2, and by 1980, this figure had merely doubled to approximately 1.9 persons per km^2.

Much of the area to the south is desert, and of the four planning regions (Tripoli, Benghazi, Khaliz and Sebha), the northern regions of Tripoli and Benghazi cover 21% of national territory and contain 88.7% of the total population, resulting in a local density of 5-6 people per Km^2. Further, the coastal strip of these two regions covering an area approximately equal to 2% of the national territory contains 75% of the total national population, including 85% of the urban and 70% of the rural components. Together these two regions comprise of 86% of the national labour force and 85% of the industrial base.

The national population is expected to grow by 88% (from 3,266,000 to 6,146,000) by year 2000 (Table 1). Approximately 92% of the increase (2,540,160) is expected to be contained in the two northern regions, whereas Khaliz and Sebha regions which comprise four-fifths of national territory are expected to grow by approximately one-quarter million.

Table 1 : Population Growth and Urbanization in Libya

Area		1954	1964	1973	1980	2000
Urban	No.	270,000	735,253	1,344,327	2,155,560	5,075,837
	%	24.8	47.4	59.8	66.0	2.6
Rural	No.	818,873	829,116	904,895	1,110,440	1,070,163
	%	75.2	53.0	40.2	34.0	17.4
Total		1,088,873	1,564,369	2,249,222	3,266,000	6,146,000

Natural increase = 3.7% per year approximately.

The urban population has increased very rapidly in the 25 years preceeding 1980. In 1954, urbanization rate was approximately one-quarter, and by 1964 the urban population had attained a level of 47% of the total population, increasing to 66% by 1980. This is a very high rate of increase in the light of the fact that the population had more than doubled by 1973, and more than tripled by 1980 respectively.

Transport in Libya is by sea, road and air. Sea transport is envisaged to play a more important role through following nine harbours:

a)	Large harbours	Tripoli, Misurata, Benghazi
b)	Middle size harbours	Zwara, Marsa Brega, Berna, Tobruk
c)	Small harbours	Sirthe, Tolmeitah (or another in the Benghazi Region).

The main forms of present land uses in National development plant have been classified as follows:

Urban	500 Km^2	0.3% of total area		
Agriculture	18500 Km^2	1.10%	"	"
Pasture land	70000 Km^2	4.00%	"	"
Forests	5000 Km^2	0.30%	"	"
Wasteland	1,666,000 Km^2	94.57%	"	"
Oil Fields	These are also indicated.			

About three quarters of the population in urban areas and cultivated rural areas are concentrated in less than 2% of the total country's area. About 1,400,000 Km^2 i.e. approximately 80% of the whole country's area consists of the desert of which half is without vegetation of any kind whilst the other half has only very limited vegetation.

The whole country's territory can be divided into five categories of suitability or non-suitability for development

i)	Preferred	32.000 Km^2	1.8%
ii)	Acceptable	135.000 "	7.7%

iii)	Possible for limited development	175.000	10.0%
iv)	Severely restricted development	300.000	17.0%
v)	Unacceptable	1.118.000	63.5%

In recent years car ownership in Libya has increased rapidly and is estimated to reach around 270 per 1000 population by year 2000. The urban form has also changed to accommodate automobile travel to such an extent that the more efficient modes of travel became impractical. The advent of commercial jet, with its fast, convenient, and nonstop service has cut dramatically into the mass transit. The dieselization of the commercial vehicle has increased the petroleum input to transportation. Lastly the urban congestion which has resulted from higher levels of travel has added to the loss of fuel efficiency. For example, in crowded areas such as CBD areas in Tripoli which have only 9% space for traffic compared to 25% in most developed cities in the world, traffic has bogged down to a very low speed Automobiles consume almost two times as much fuel per 8 Kmph than at 48 Kmph.

4. SUGGESTED APPROACH FOR REDUCING FUEL CONSUMPTION:

There are a variety of alternative methods which if implemented can reduce the consumption of petroleum fuels. These are: (a) reduce overall demand, (b) shift demand to more energy efficient modes, (c) increase occupancy of vehicles, (d) increase vehicle efficiency and (e) improve traffic operations. Great Jamahiriya needs to define the best combination of these methods, keeping in mind social and economic costs and community expectations.

4.1 Reduce Overall Demand for Transportation:

Directly reducing the overall demand for transportation services is an extremely difficult task. Given the present land use configuration and the economic and demographic characteristics of the population, travel demand in Great Jamahiriya is expected to remain high. The long-range outlook will undoubtedly lead to changes in land use. There is consequently a need for long term urban planning aimed at the development of integrated communities combining residential, work and recreational activities. Many of the auto trips currently made for business or shopping could in time be rendered unnecessary by advanced telecommunications. Pricing policies and regulation may be used to alter the travel behaviour of individuals.

4.2 Shift Demand to More Energy Efficient Modes of Transport:

Theoretically, a shift in demand from automobile to more efficient mass transit modes in cities would achieve not only energy conservation, but also a reduction of traffic congestion, noise levels, and atmospheric pollution. It has been found that if 10% of the automobile passenger trips are shifted to transit, ridership would double on the nation's public transport

system. In short term, due to extremely low ridership in the Great Jamahiriya, the use of transit facilities will not be able to contribute substantially to the reduction of fuel consumption. In the long run, in order to get people to shift from automobile to transit, a combination of automobile distinctives and transit incentives will be necessary. Otherwise, transit improvements will only attract the non-auto owner and thus fail to save energy. The use of private cars can be discouraged by establishing car-free or limited access zones, reducing the parking supply and the level of public subsidies for parking, or establishing tolls for entry into congested areas.

As per one of the estimate around 60% of all urban trips in Great Jamahiriya are less than 5 Km, walkable short trips account for only 15% of all travel. If all of these trips could be converted from auto trips to walking and bicycling, a considerable amount of fuel could be conserved annually. The provision of adequate walkways and bicycle paths would make these alternatives more attractive.

4.3 Promotion of Increased Vehicle Occupancy:

The average car occupancy in Libya is around 2 persons per car. Considering that most cars have a seating capacity for 4 or 5 people, a large inefficiency exists. About one third of auto travel is work oriented. There are a variety of following policies which could be used to promote increased vehicle occupancy.

1. Preferential traffic control techniques, giving priority to high-occupancy vehicles.
2. Preferential parking.
3. Ridersharing and carpooling education and marketing programs;
4. an information system which will give commuters an up-to-date list of all those with whom they can share rides to and from work.

Table below shows how operating energy can be reduced and efficiency increased with an adequate ridesharing program.

Table: Energy Requirements by Urban Travel Modes (Btu per Passenger Mile)[a]

Mode	Operating energy[b]	Model energy[c]	Program energy[d]
Single occupant automobile	11,000	14,220	Not Applicable.
Average automobile	7,860	10,160	" "
Car Pool	3,670	5,450	4,890
Van Pool	1,560	2,420	7,720
Bus	2,610	3,070	3,590[e]

Source: From U.S. Congress, 1977."Urban Transport and Energy:

The Potential Savings of Different Modes". Washington, DC: Budget Office.

a. mile = 1.6093 km; Btu = 1055.1 Joule

b. Propulsion only

c. All forms of energy, computed on a door-to-door basis, adjusted for roundabout journeys.

d. Energy saved (lost) per passenger mile of travel induced by new programs.

e. For new express bus service. Regular urban bus service would show smaller savings.

The use of larger trucks with higher ton-mile/gallon ratio and high occupancy vehicle can increase energy efficiency at added system and social costs. Critical roads would have to be strenghened since pavement wear would increase substantially. Larger trucks also represent a safety hazard on the road. The larger, heavier trucks move more slowly relative to other traffic, causing congestion.

4.4 Utilization and Improvement in Vehicle Efficiency:

The demand for energy can be reduced by utilization of technological advances in engine design and vehicle weight. Smaller, more economical automobiles are being regulated to produce models that meet minimum fuel consumption standards. The diesel engine is capable of achieving 75% better fuel economy than the average vehicle of the same weight equipped with a conventional engine. Of course, there are drawbacks to the diesel engine. It is noisier than the conventional engine, its exhaust has a more unpleasant odor, it emits heavy particulate matter into the atmosphere, it ismore difficult to keep in tune, and it is more expensive. Small cars have more freedom of mobility. Vehicles attain their highest fuel efficiency at the lowest possible steady speed in the higher gear, typically between 50 and 80 Kmph. Reducing speeds is one policy that may be implemented in Jamahiriya. Additional ways of improving the efficiency of automobiles include traffic flow improvements and vehicle inspection programs that require engine tune-ups.

4.5 Improving Traffic Flow and Operations:

Improvements in traffic flow reduces the amount of delay and fuel consumption associated with stop-and-go driving . Transportation system management (TSM) technique increases the capacity and efficiency of urban traffic facilities using low-cost improvements that can be implemented within a reasonable period of time with no additional right of way requirements. It includes improvement such as signalized intersections, freeway ramp metering, one way streets, removal of curb parking, reversible lanes, traffic channelization, and transit stop relocation.

5. CONCLUDING REMARK:

The paper has highlighted the necessity for the government industry, and the general public to be keenly aware of the need to conserve energy and energy-related resources. The development of numerous energy-saving strategies by both the public and private sectors are given. The conservation alternatives discussed include changes in individual travel behavior physical and operational changes in the transportation network, and policy changes. The integrated approach defining the best combination of the conservation measures considering mobility and socioeconomic costs related to the measures to overall goals are presented. It is found that in order to establish and maintain strict energy saving principles there is need to modify urban structure and lifestyle to facilitate transportation energy conservation.

REFERENCES

1. U.S. Department of Transportation,"Energy Statistics Supplement" Washington, D.C.: Annual (Supplement to summary of National Transportation Statistics, but issued separately - 1977.

2. Faucett, J., "Impact of the Transportation Energy Shortage" Washington D.C., U.S. Department of Transportation, 1973.

3. Bindra, S.P. "A Course in Highway Engineering", Dhanpat Rai and Sons, Delhi, India, 1988.

SECTION V

POWER SYSTEMS AND MAINTENANCE

THE EFFECT OF ENERGY INPUT ON PRODUCTIVITY MEASUREMENT AT MANUFACTURING INDUSTRY

by

Dr. Abulghassem M.M. Elshake
Higher Institute of Mechanical & Electrical Engineering
Hoon, Libya.

Abstract

Energy input consumption is an important component in the productivity measurement concept since energy-related cost have been increasing faster than the rate of inflation.According to all forcasting, the cost of energy will continue to grow in the future and industries differ greatly in their energy use profile due to such variables as location,whether, number of people, product manufacturing intensity as well as many others.

This paper, presents the method of measuring total productivity for an industry, energy input measurement; single-productivity of energy input. A numerical example is provided to illustrate the energy productivity models and the effect of energy input in total productivity in production system. Some valuable and useful information for industrial managers in their decision making process can streamline and improve productivity also will be highlighted.

1. PRODUCTIVITY MEASUREMENT

The subject of productivity measurement at the industrial level has been receiving increasing attention. A study by Hawaleshka & Mohamed (1985) has classified the major work on productivity measurement, based on the following criteria.

a. Output and input elements;
b. Purpose of measurement;
c. Function of productivity index;(minimization of cost, maximization of profit, or evaluation of industries.)
d. Method of measurement(econometric, industrial engineering, accounting.)

Industrial Productivity Measures fall into five basic categories.

a. Single factor productivity (SFP)
b. Multifactor productivity (MFP)
c. Total productivity (TP)
d. Managerial control ratio (MCR)
e. Productivity costing (PC).

Since the SFP is the wide type of measure is used, its merit is essentially designed to measure the ratio of an output to one input factor of production.

While TP measures the effects of change of total output relative to the change of all inputs as recommended by Kendrick (1965), Craig - Harris (1973) Mudel (1976), Sink (1983), Samenth (1984) and Mohamed (1986). Their proposed TP measures differ through their use of product line productivity summations in the computation of output and inputs, comparisons of the actual TP to standard TP, inclusion of price and cost factors in the output and inputs, and measuring the total output to operational input in all cases TP is measured in constant Libyan Dinners (L.D) units at any period of time.

2. TOTAL OPERATIONAL PRODUCTIVITY DEFINITION :

Operational productivity is defined as the total ratio of the total quantified value of shipments of manufactured goods to the total quantified value of human effort , capital, input, energy costs and supplies, and other costs consumed in a given time, in terms of constant L.D.

3. TOTAL OPERATIONAL PRODUCTIVITY FORMULATION:

A. OUTPUT ELEMENTS:

Revenue from finished product sales

a. (Quantity shipped) (current selling price)

(Selling price deflation index)

Where, selling price deflation index = (Current selling price)

(Base period selling price)

b. Revenue from repair: is the amount of income from repair and service to other manufacturers.

c. Work done on material owned by others.

d. Other income: such as interest from investments.

e. Ancillary Expenses: sales taxes, discounts and similar items must be subtracted from the above.

B. INPUT ELEMENTS:

a. Production and related Workers: employee in manufacturing operations, other production workers, executive staff, sales staff and administration. All are determined in terms of value in constant dollars.

b. Capital: Fixed capital consumption of: Machinery and equipment, building construction, engineering construction, and capital items charged to operating expense. Working capital consumption: Inventory, accounts receivable, notice receivables and cash in constant dollar.

c. Material and supplies: Raw material, purchased materials used in manufacturing operations, total value of operating maintenance and repair supplies purchased and used in mfg. operations excluding fuel in constant dollars.

d. Energy: Coal and coke, natural gas, gasoline, kerosene, stove oil, diesel oil, light fuel oil, heavy fuel oil, electricity purchased and other fuels including steam purchased.

e. Other costs: Travel, R & D, and marketing.

The data base for outputs and inputs proposed in 1&2 above can be collected for one industry or for certain time periods. Often such data is available from official statistical sources. Thus the Total Operational Productivity is given by:

$$TOP_{it} = \frac{\sum_{k=1}^{K} Y_{itk}}{\sum_{j=1}^{J} \sum_{l=1}^{L} X_{itjl}} \qquad (1)$$

Where

TOP_{it} = Total operational productivity measure in industry i during time t.

Y_{itk} = Amount of output shipped from industry i during time t for output type k, (K=a,b,c,d,e as specified in A above)

X_{itjl} = Amount of input consumed in industry i during time t, for input j. J = Human, capital, material, energy and other costs. L = are the elements of each J, as specified in input elements.

Total Operational Productivity Index ($TOPI_{it}$) is given by

$$TOPI_{it} = \frac{TOP_{it}}{TOP_{it-1}} \qquad (2)$$

Where t refers to the current period and t-1 refers to the reference or base period, (t = 1,2, ... T). Other operational productivity measures such as single and multifactor can be given in the same manner.

5. ENERGY PRODUCTIVITY:

Energy consumption is an important component in the Total Operational Productivity concept since energy-related cost have been increasing faster than the rate of inflation. According to all forecasts, the cost of energy will continue to grow in the fiture. In considering "energy productivity" (one of the typical single factor productivity measures), Turner and Parker (1984) concluded that this was very difficult to monitor. This is mainly due to lack of appropriate metering, poor energy usage and poor energy cost data maintained by typical industries. Industries differ greatly in their energy use profile due to such variables as location, wheather, number of people, product manufacturing intensity, as well as many others. Energy input can be measured in Total Operational Productivity by:

$$= \frac{\text{Total energy input in current dollars}}{\text{Energy cost index}} \qquad (3)$$

or, in an expanded fashion, by detailed listing such as:

$$\frac{\text{Coal + coke + natural gas + gasoline + kerosene + diesel oil + light fuel oil + heavy fuel oil + electricity purchased + other fuel including steam.}}{\text{Energy cost index}}$$

CASE STUDY:

Of Canada's metal-working group of industries, the metal fabricating sector is the second largest employer with approximately 135,000 employees producing equivalent to 30 billion L.D. of output per year (1984).

To illustrate the benifit of productivity measurement and the effect of energy, input factor, a primarily data from statistics Canada has been worked out and summerized in Table 1 for output and inputs.

According to Eq. (1) & Eq. (2) and Eq. (3) calculations and analysis of all single factor productivities includes energy input are presented in Table (2).

The variability of energy productivity with respect to total productivity is presented in figure 1. A linear regression analysis has been fitted to explain the relationship between total operational productivity and energy input productivity as shown in Fig. (2).

From the above analytical information it does seem that energy input has a close relationship to total production . This can effect the attitudes of top management and productivity staff to stress of saving energy and using accurate metering system at manufacturing floor shop from the poing of view of productivity measurement concept.

REFERENCES:

1. Craig, C.E. and Harris, C.R. Total Productivity Measurement at the firm level, Sloan Management Review, 1973 14(3), 13-29.
2. Hawaleshka, O. and Abulghassem M. Mohamed, "Productivity Measurement based on the Technology Factor Index" . Proceedings of Industrial Engineering Conference " '85 Chicago, Illinois, USA.
3. Kindrick, J.W and Creamer , D. Measuring Company Productivity: hand book with case studies. New York, USA, 1965.
4. Mohamed, Abulghassem M. "Productivity Measurement and Planning Models for Manufacturing Industries. Ph.D. dissertation, 1986, Department of Mechanical Engineering, University of Manitoba, Winnipeg, Manitoba, Canada.
5. Mundel, M.E. Measures of Productivity Industrial Engineering, 1976,
6. Sink, D.S. Organizational system performance is productivity a critical component?" Institute of Industrial Engineers 1983 annual Conference Proc. Norcross, GA.
7. Sumanth, D.J. " Productivity Engineering and Management" 1984, McGraw-Hill inc., New York, N.Y.
8. Turner, W.C. and S.A. Paker, "Energy Accounting: A New Field Develops, IIE, Transaction, 1984, Vol. 16(12), pp. 135-143.

Table 1. Output and Input data, metal fabricating industries in Canada, 1971 dollars.

OUTPUT AND INPUT VARIABLES

TIME YEAR	OUTPUT VALUES	EMPLOYEE R.WORKER	CAPITAL CONSUMPTION	MATERIAL SUPPLIES &	FUEL ELECTR	OTHER COST INPUT VALUE
1971	3522.00	716.39	96.20	1613.90	35.53	35.20
1972	3650.50	748.57	100.30	1676.00	41.24	34.40
1973	4032.14	798.10	104.60	1875.02	34.00	49.50
1974	4324.20	790.82	109.50	2016.35	52.05	43.20
1975	3875.90	875.14	114.10	1855.51	39.14	45.70
1976	4197.80	852.18	118.20	1935.08	39.94	45.90
1977	4202.10	843.20	121.00	1930.85	34.03	37.40
1978	4511.20	820.14	122.80	2101.59	39.81	29.50
1979	4915.80	705.92	125.20	2305.40	42.12	38.80
1980	5117.16	737.95	129.20	2168.32	42.69	34.90
1981	4853.10	767.88	132.60	2243.92	38.09	39.85
1982	4160.90	542.59	134.30	1483.09	38.28	40.00

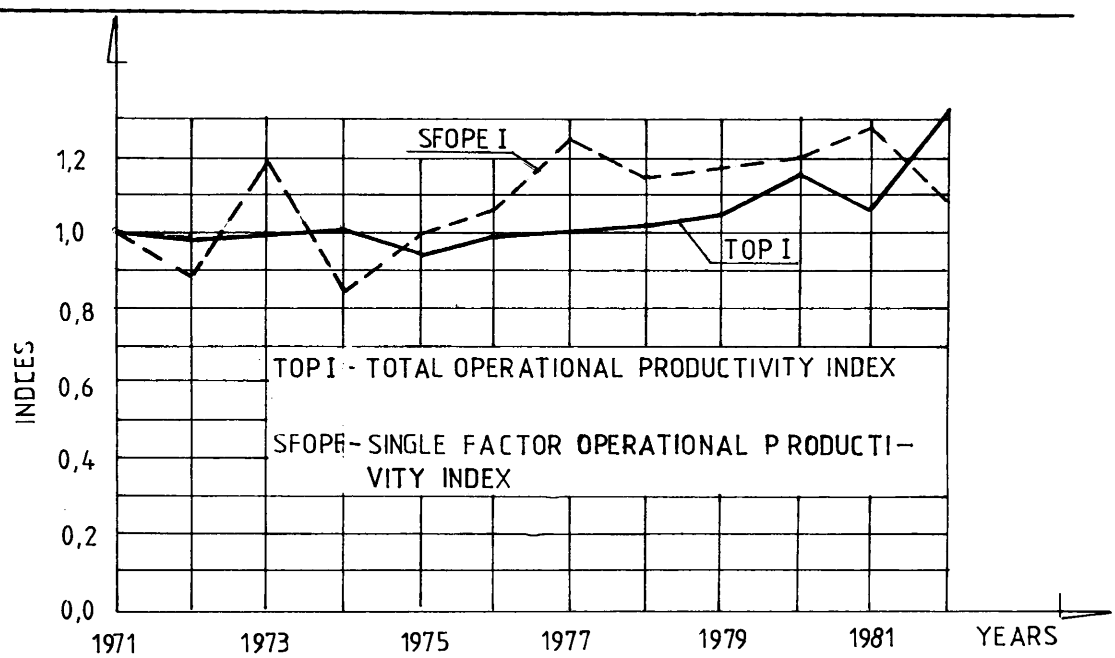


FIG.1. PRODUCTIVITY INDICES

Table 2: Single Factor Operational Productivities in Canadian Metal Fabricating Industries.

SINGLE OPERATIONAL PRODUCTIVITY MEASURES					
YEAR	SFOPH	SFOPC	SFOPM	SFOPE	SFOPO
1971	4,9163	36.6112	2.1823	99.1275	100.0568
1972	4.8766	36.3958	2.1781	88.475	100.2885
1973	5.0522	38.5484	2.1505	118.5929	81.4578
1974	5.4680	39.4904	2.1446	83.0778	100.0972
1975	4.4289	33.9693	2.0889	99.0266	84.8118
1976	4.9260	35.5144	2.1682	105.1027	91.4553
1977	4.9835	34.7281	2.1763	123.4822	112.3556
1978	5.5005	36.7362	2.1466	113.3183	152.9220
1979	6.2548	39.2636	2.1321	116.7094	126.6959
1980	6.9342	39.6060	2.3599	119.8665	138.6748
1981	6.3201	36.5995	2.1628	127.4114	121.7842
1982	7.6686	30.9821	2.8056	108.6964	104.0225

SFOP = Single factor operational productivity
H = Human
C = Capital
M = Material
E = Energy
O = Other costs

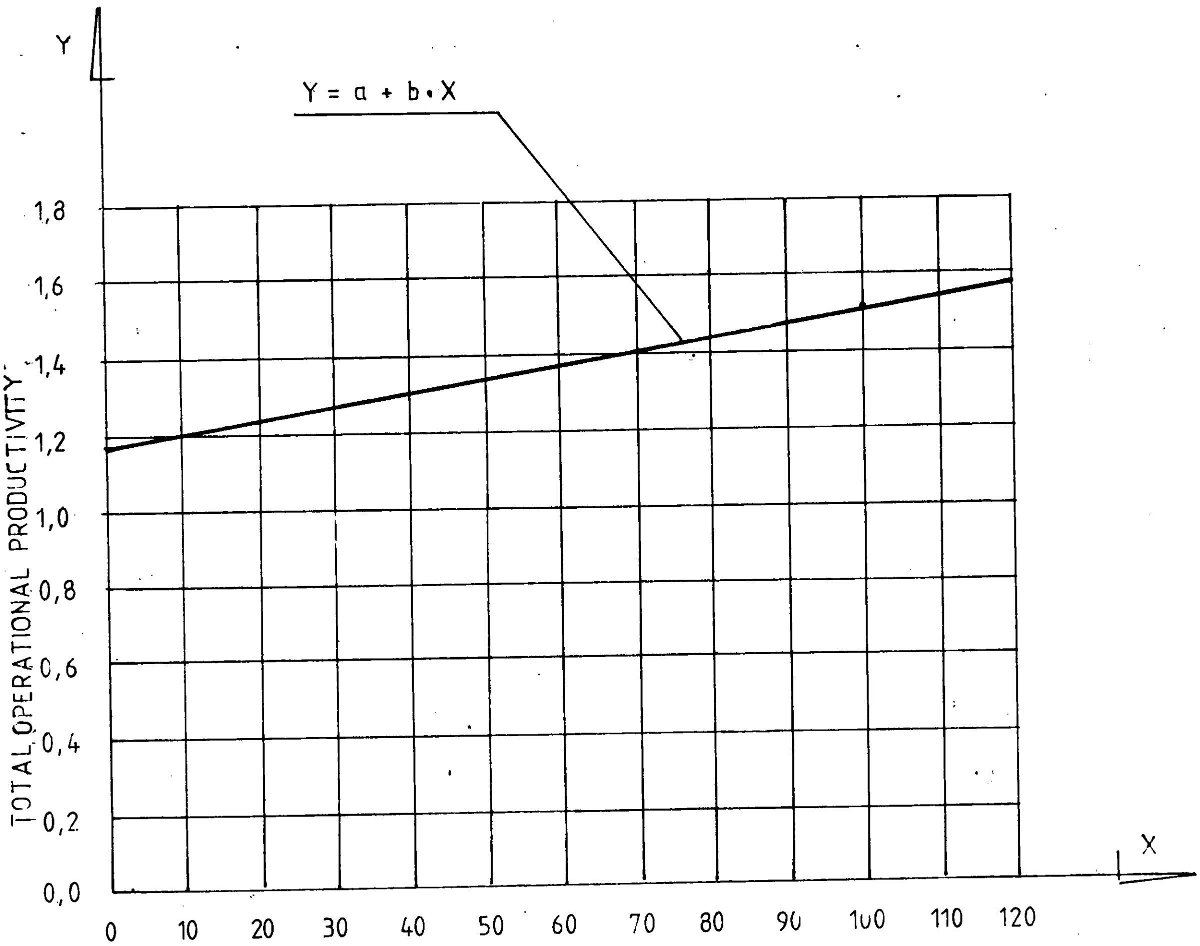


FIG.2. RELATIONSHIP BETWEEN TOP AND SFOPE

SUITABILITY OF DRY COOLED POWER PLANT IN LIBYA

M. Sassi, F. A. Ansari, A. Geddem*

Mechanical Engg. Dept.,Raya-El-Khadra University,
Tripoli, G.S.P.L.A.J.
* G. E. C., Tripoli, G.S.P.L.A.J.

ABSTRACT

Libyan General Electric Company is planning to install some small dry cooled power plants in the regions where natural water is scarce. A feasibility study is made for such a power plant. For most of the desert areas, during the winter season and summer nights, wind speed is high and ambient temperature is sufficiently low. Both these features are desirable for dry-cooled power plants. During summer days, the temperature of the ambient air is very high which will make heat transfer rate low. A gas and steam combined cycle power plant is proposed with air-cooled condenser. During winter season and summer nights cold ambient air flows directly across the condenser tubes. During hot summer days it is precooled in an underground tunnel.

1. INTRODUCTION:

The once-through direct water cooled systems are found to be most economical, but the regulations for rise of temperature and pollutants make such systems undesirable. Due to these reasons, there are very few sites where direct water-cooling is employed. Wet cooling towers have been used for many years in practically all countries of the world. In wet cooling towers, the minimum theoretically attainable temperature is the wet bulb temperature of air. The cooling rate is a function of approach which is the difference in the temperature of cold water and the wet bulb temperature. For large units natural draught cooling tower has proved to be more economical compared to the mechanically induced draught system [1] .

In dessert areas, natural water is scarce and even the make up water needed in wet cooling towers becomes very costly. A dry-cooled power plant may prove to be more economical and practicable in such areas. During extremely hot periods the air may be precooled by passing it through a deep wetted underground tunnel where its temperature is lowered down partly due to cold soil mass and partly due to evaporative cooling. Studies of the underground soil temperatures have shown that at a depth of 3 to 5 meters the temperature during summer is 20 to 22°C [2] . The temperature may be still lower if the earth surface is kept well shaded and wet [3] . A thorough heat and mass transfer analysis of underground air tunnels has been presented by

Goswami et al. [4] . The use of this principle of environmental control is not new. It had been used in ancient times in Libyan, Iranian and Tunisian buildings [5, 6] .

2. AIR COOLED POWER PLANTS:

Both a direct air condensing system and an indirect cooling system have been successfully used in power plants with capacities varying from 15 MW to 330 MW. In a direct air-condensing system the turbine exhaust steam is admitted to the air-cooled heat exchanger elements and condenses there. In the indirect dry cooling system, the steam is condensed in a water circulated condenser and the circulating water is cooled in a closed circuit by air-cooled heat exchanger. Due to its simplicity, low initial and running costs and minimum maintenance requirement, the direct air-condensing system is preferred.

The first air-cooled condenser was used in a 1.5 MW steam turbine in West Germany in the year 1939 [7] . The first dry cooled power plant was commissioned near Perugia, Italy in 1958 which had a nominal output of 76 MW. In 1960 a 96 MW air-cooled plant was started in Wolfsburg, West Germany. In the same country, a 15 MW Nuclear Test Reactor Plant was built in 1960 at Julich,a 133 MW air-cooled system was started in 1969 at Mannheim and a 600 MW unit is designed for THTR Nuclear Power Plant at Uentrop. In France, a 64 MW air-cooled plant was commissioned in 1968 at Gonfreville and another 64 MW plant was started in 1969 at La Mede. A 300 MW unit with direct air-cooled condensers is under construction at Mashad, Iran.

Comparative study of published data shows that the direct cooled system has higher net efficiency compared with indirect air cooling system [1] . In fossil fuelled power stations, the capital cost of an indirect cooling system would be nearly 15% more than that for direct cooled condenser while for nuclear power stations it is nearly 25% higher. The operating cost would be 8.5% higher in case of indirect cooling fossil fuelled power plants and it would be 20% higher for indirect cooling nuclear power plants. Due to the aforesaid factors, a direct air-cooled system must get preference.

In most desert regions of Libya, ambient temperature is below $10^{o}C$ during winter and average wind speed is 5-8 m/s. Summer nights are also very cold and ambient temperature is below $20^{o}C$. Therefore, during winter season and at summer nights, direct ambient air stream may be used for dry cooling of condensers. contrary to this, the summer days are very hot and sometimes the ambient temperature is higher than $45^{o}C$. This will sharply decrease the heat transfer rate from heat exchanger to the ambient air. Fortunately, the relative humidity during summer is very low which makes the evaporative cooling of air very effective. If the ambient air is first allowed to pass through a 3 to 5 m deep underground tunnel, the temperature of outlet air may be achieved which is less than $20^{o}C$. This precooled air may be allowed to pass through the condenser tubes of dry cooled units.

3. BASIC EQUATIONS:

If air is passed through a deep underground tunnel, the temperature of the pre-cooled air can be calculated from the equation;

$$T(x,t)= T_m-A_s.e^{-x(\frac{\pi}{\alpha}.365)^{\frac{1}{2}}}.\mathrm{Cos}\left[\frac{2\pi}{365}(t-t_o-\frac{x}{2}(\frac{365}{\pi\alpha})^{\frac{1}{2}})\right] \qquad (1)$$

This will be the inlet air temperature to the condenser in which isothermal

condensation of steam takes place corresponding to the condenser back pressure.

The rate of heat transfer from the steam to the air stream is given as:

$$Q = A_t \cdot U_m \cdot \Delta T_{ln} \tag{2}$$

The calculation of rate of heat transfer requires the knowledge of heat transfer coefficient (U_m). For the laminar region, the extended equations by Nusselt [8] will give satisfactory results. For pseudo-laminar flow the equation of Carpenter and Colburn [9] would be appropriate and for turbulent condensate films the Dukler equations [10] are preferred.

4. SYSTEM LAYOUT:

From the point of view of energy conservation, a steam and gas combined cycle power plant is proposed. In a simple cycle gas turbine plant, the turbine exhaust gas temperature is 490 to 530 °C which is discharged to atmosphere. Part of this waste heat can be recovered by using a heat recovery steam generator (HRSG) on the gas turbine exhaust path. The steam generated in this waste heat boiler is used to drive a steam turbine. Such a combined cycle system is shown schematically in Fig. 1. The power output is increased by 50% for the same fuel consumption compared with a simple cycle power plant [11]

One unit of a condenser group suitable for such a plant is shown in Fig. 2. It consists of two condenser modules C and one dephlegmator module D located in the centre of the group. Steam passes through the cooling elements of C-modules co-current with the condensate which is formed on its way down. Nearly 75% of the steam is condensed in C-modules. The remaining steam is condensed in the D-module. Subcooling is prevented in the D-module due to counter-current flow of steam and condensate. The non-condensables are evacuated at the top of D-module by means of vacuum ejectors.

The condenser group is enclosed in a vertical tunnel which is an extension of a 3-5 m deep underground horizontal tunnel 10 m long. A shutter is provided and arranged in such a way that during winter season and cold summer nights, the ambient air is allowed to enter the condenser directly and the passage of the underground tunnel is blocked. During hot summer days the shutter is positioned in such a way that it inhibits the direct entrance of the ambient air and opens the underground tunnel passage. The ambient air first passes through the underground tunnel and it is precooled before entering the condenser space. The back pressure is maintained in the range 4 and 8 in Hg A. This is achieved by controlling the air-flow rate with a combination of fan speeds, varying from zero to maximum, to meet most of the load and ambient temperature conditions. The station output will vary with the ambient temperature as shown in Fig. 3 for a typical 330 MW fossil fuelled power plant.

The best location of the condenser group will be near the ground level. Detailed design of the aforesaid dry-cooled power plants is possible only after making a thogough analytical and experimental investigations, particularly with respect to the underground tunnel. Optimum tunnel diameter, length, perimeter to length ratio, depth and number of parallel tunnel arrangements must be determined for a particular prospective location of the dry cooled power plant.

5. CONCLUSION:

It is possible to design and construct low and medium sized dry-cooled power plants. To optimise the power output, a gas and steam combined-cycle system will be suitable. A direct air-condensing system is preferred. In the regions where winter wind speed is sufficiently high and summer nights are very cold, ambient air may be passed directly through the condenser tubes. During the hot summer days the air is first precooled by passing it through a 3-5 m deep wetted underground tunnel.

6. NOTATIONS:

A_s	annual temperature amplitude at soil surface, ^oC
A_t	total area of heat exchanger, m^2
Q	total heat transfer rate, W
t	time of year in days.
t_o	the day of the minimum surface temperature
T_m	mean annual ground temperature, ^oC
U_m	average overall heat transfer coefficient, $W/m^2.K$
x	depth of the ground, m
α	thermal diffusivity of soil, m^2/day
ΔT_{ln}	Logarithmic mean temperature difference between the steam and cooling air, K

7. REFERENCES:

[1]-Blanck, D., "The Economics of Closed-Circuit Cooling Systems",English Translation from Technische Mitteilungen-Organ des Hauses der Technik e.v., Vol. 65, No.5, 211-214, May (1972).

[2]-Khatri, A.K., Sodha, M.S. and Malik, M.A.S., "Periodic Variation of Ground Temperature with Depth", Solar Energy, 20, 425-427 (1978).

[3]-Bansal, N.K., Sodha, M.S. and Bhardwaj, S.S., "Performance of Earth Air-Tunnels", Energy Research Vol.7, 333-345 (1983).

[4]-Goswami, D.Y. and Dhaliwal, A.S.,"Heat Transfer Analysis in Environmental Control Using an Underground Air Tunnel", J. Solar Energy Engg. Vol. 107, 141-145, May (1985).

[5]-Bahadori, M.N.,"Passive Cooling Systems in Iranian Structures", Scientific American, Vol. 238, No. 2, Feb. (1978).

[6]-Cole, R. and Kennedy, R.,"Passive Energy in Historical Tunisia", 5th NPSC, J. Hayes and R.Snyder eds., AS/ISES, Newark, Delaware, 704-706 (1980).

[7]-March,F. and Schulenberg, F.,"Air-cooled Condenser for a 160 MW Steam Power Station, Planning of the Plant and Experience Gained in Two years of Operation", Translated from Spanish Magazine Dyna/Revista de la Asociacion Nacional De Ingenieros Industriales De Espana, Sept. (1972).

[8]-Nusselt, W., "Die Oberflöchenkondensation des Wasserdampfes", VDI-Zeitschrift, 60, 569-575, (1916).

[9]-Carpenter, E.F. and Colburn, A.P.,"The Effect of Vapor Velocity on Condensation inside Tubes", Proc. Gen. Discussion Heat Transfer, London, 20-26, (1951).

[10]-Dukler, A.E., "Fluid Mechanics and Heat Transfer in Vertical Falling-film Systems", Chem. Eng. Progress Symp. 56, 1-10 (1960).

[11]-Lugand, P.,"Gas Turbine Power Plant Conversion into Combined-Cycle", Alsthom Review No. 5, 3-14 (1986).

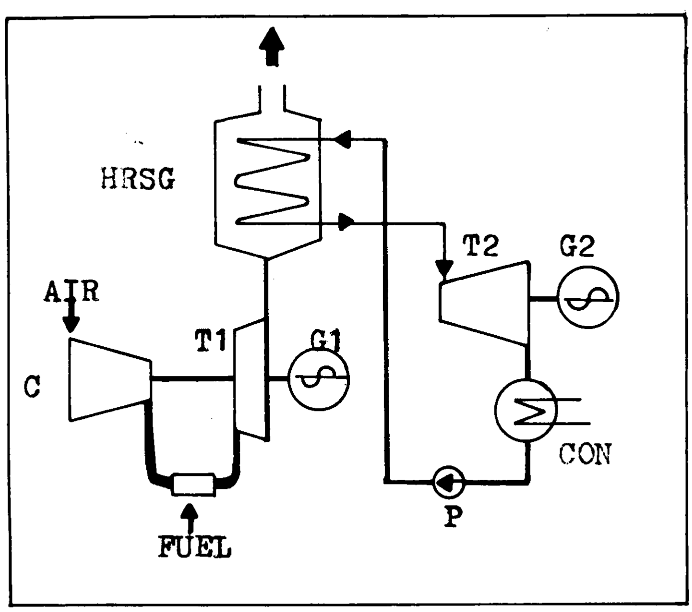


Fig. 1. Schematic of combined-cycle power plant.

C-Compressor
CON- Condenser
G1, G2- Generators
P- Pump
T1- Gass Turbine
T2- Steam Turbine

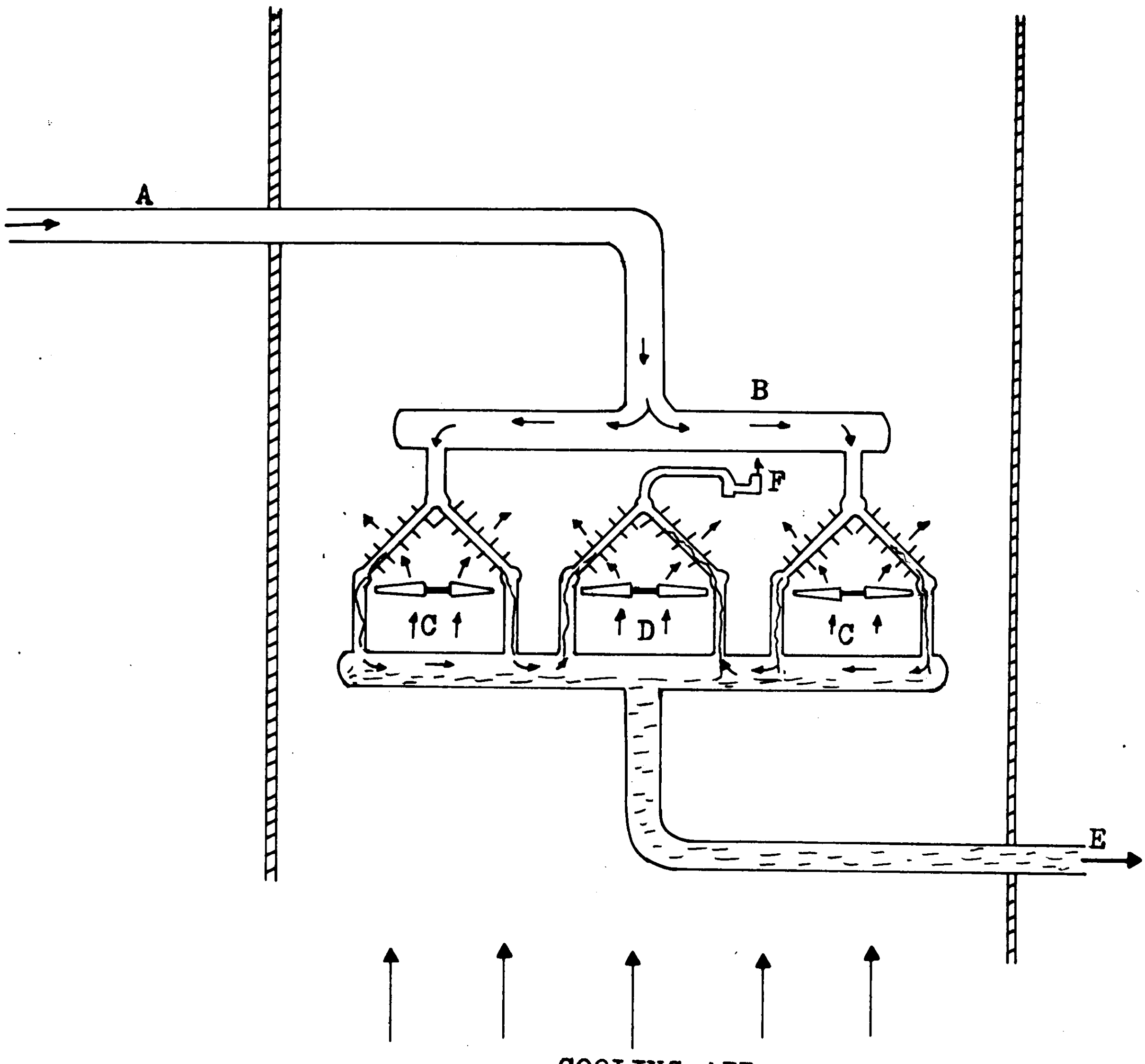


Fig. 2. Schematic of condenser system

A– Turbine Exhaust Pipe
B– Steam Distribution Manifold
C– Condensers
D– Dephlegmator
E– Condensate Pipe
F– To Vacuum Ejector

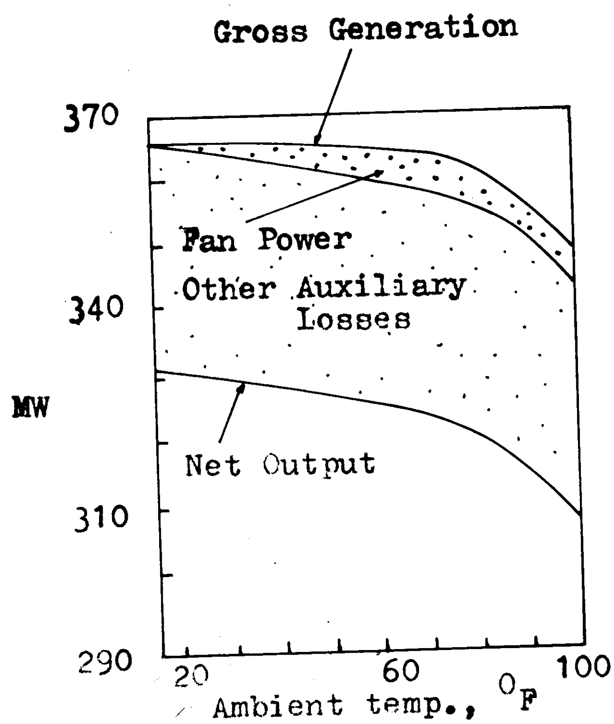


Fig. 3. Variation of Power with ambient temp.

TRANSIENT TEMPERATURE ANALYSIS IN A SYSTEM OF THIN SHELLS COMBINED WITH CONVECTIVE AND RADIATIVE COOLING

Ravindra Prasad and N.K. Samria
Department of Mechanical Engineering
Banaras Hindu University
Varanasi-221 005(INDIA)

1. ABSTRACT

The problem considered has applications in the transient thermal analysis and time for attaining the steady state of the cylinder wall and cylinder head of an air-cooled internal-combustion engine. Numerical calculations based on finite difference approximations are carried out to assess the thermal response in a system of thin cylindrical and spherical shells having hot gases inside with convective boundary conditions. The outside surface is exposed to cooling medium where it looses heat by natural convection and radiation. As a special case, when radius is large, the surface may be considered to be a plane wall. The cylinder cover and cylinder wall of an internal combustion engine are considered to be a plane wall for a comparatively higher ratio of cylinder diameter to the thickness of the wall i.e. when d/δ varies from 80 to 100. A plot of temperature-time history and heat flow rates have been obtained.

2. NOMENCLATURE

A	..	surface area (m^2),
a	..	thermal diffusivity (m^2/s),
B_g, B_c, B_r	..	Biot's numbers on inner and outer surfaces,
c	..	specific heat ($KJ\ kg^{-1}\ K^{-1}$),
d	..	diameter of engine cylinder (m),
F_o	..	Fourier's number $F_o = a\ t/\delta^2$
h_c	..	heat transfer coefficient due to natural/forced convection ($W\ m^{-2}\ K^{-1}$),
h_g	..	heat transfer coefficient of hot gases ($W\ m^{-2}\ K^{-1}$),
h_r	..	heat transfer coefficient due to radiation

	.. ($W\ m^{-2}\ K^{-1}$),
k	.. thermal conductivity ($W\ m^{-1}\ K^{-1}$),
M	.. dimensionless temperature, $M = T_6 / T_\infty$,
Q	.. heat flow rates (KW),
Q_g, Q_c, Q_r	.. amounts of heat flow to and from the shells (KW) as shown in fig. (1),
Q^*	.. amount of heat absorbed by the shell for warming up (KJ),
q_g, q_r, q_c	.. heat fluxes to and from plane wall ($KW\ m^{-2}$) as shown in fig. 3 (c),
q^*	.. amount of heat absorbed by the plane wall for warming up ($KJ\ m^{-2}$),
r	.. radial co-ordinate (m),
R_1, R_2	.. inner and outer radii (m),
R	.. subdivision thickness of the shell (m) as shown in fig. (2),
t	.. time (s),
T_o	.. initial temperature of the shell (K),
T_s, T_g, T_∞	.. outer surface, gaseous and ambient temperatures,
T_1, to T_6	.. temperatures (K) as shown in fig. (2),

Greek Symbols

δ	.. thickness of the shell, $\delta = (R_2 - R_1)$, (m),
ρ	.. density ($kg\ m^{-3}$),
σ	.. Stefan - Boltzmann constant ($W\ m^{-2} K^{-4}$),
ϵ	.. emissivity of the surface for radiation,

Superscripts

j, j+1	.. represent values of temperatures at jth and j+1th time steps.

3. INTRODUCTION

The study of heat transfer process in the parts of Internal Combustion Engines under unsteady state conditions becomes much more complicated when one of the surface is loosing or gaining heat by radiation. The situations met in an air-cooled engine which is loosing heat by combined mode of natural convection and radiation is a realistic problem. The outer surfaces of an air-cooled engine always loose heat by radiation and by convection. Since the radiative heat transfer coefficient is dependent on the cubic power of the surface temperature, the problem becomes

highly nonlinear. Analytical solutions to these problems are difficult to obtain and sometimes not even exist if more or less rough approximations are not used.

Transient heat conduction in a solid with complicated thermal boundary conditions has received little attention in literature. Croshie and Viskanta [1] analysed transient heating and cooling of a plate by combined convection and radiation. They presented a review of studies dealing with a heat conducting solid exposed to combined convection and radiation. Davies [2] studied the transient conduction in a plate heated by convection and cooled by radiation. Recently, Bengt Sunden [3] presented an investigation where transient heat conduction in a composite slab heated by a time-varying incident heat flux and cooled by combined convection and radiation was presented.

In the present work, the authors have attempted to solve one - dimensional unsteady state problems applied to the plane wall, cylindrical wall and spherical wall of an air-cooled internal combustion engine inside which exist hot gases and outside of which is exposed to ambient air at its free stream velocity such that natural/forced convection heat transfer coefficient is 58.15 $W \ m^{-2} \ K^{-1}$ while the radiative properties of the surface are given in Table (1). Two cases have been considered, (i) when the wall is made of cast iron (ii) when wall is made of aluminium.

The purpose of this paper is to predict the transient temperature distribution, heat flow rates and the time for attaining steady states in the plane, cylindrical and spherical wall of an air-cooled engine. Due to the complexity of the problem, a numerical solution by finite difference approximations is presented.

Table 1 : Thermophysical properties of wall materials

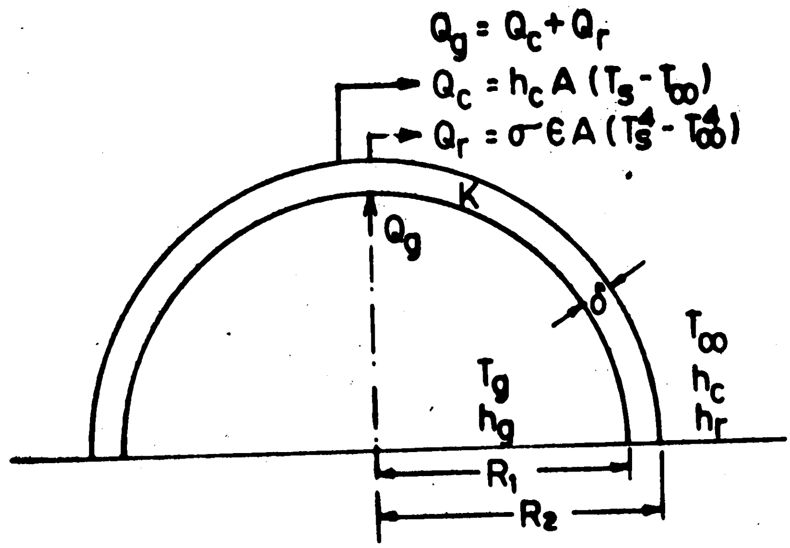
	Properties	Units	Cast iron	Aluminium
a,	thermal diffusivity, ($\times 10^6$)	$m^2 \ s^{-1}$	12.6844	70.1712
k,	thermal conductivity	$W \ m^{-1} K^{-1}$	53.50	174.40
ρ,	density	$kg \ m^{-3}$	7200.00	2700.00
c,	specific heat	$KJ \ kg^{-1} K^{-1}$	0.5858	0.9205
ϵ,	emissivity	-	0.80	0.05

4. STATEMENT OF THE PROBLEM

The problems considered in this paper are concerned with the modelling of the starting process of an air-cooled internal combustion engine. There are two types of starting (i) cold starting (ii) hot starting. In the cold starting, the body

temperature of the parts of the internal combustion engines is equal to that of atmospheric temperature i.e. engine has been started after a quite long elapse of time after being shut down, while in hot starting, engine body temperature is above that of atmospheric temperature or engine has been started after a short elapse of time after being shut down. In the present paper, the authors consider cold starting of the engine.

Figure (1) shows the general description of the problem where when $r \rightarrow \infty$, the problem reduces to that of plane wall.



$T_g = 1273$ K

$h_g = 290.75$ $Wm^{-2}\ K^{-1}$

$T_\infty = 300$ K

$T_0 = 300$ K

$h_c = 58.15$ $Wm^{-2}\ K^{-1}$

$\sigma = 5.67 \times 10^{-8}$ $Wm^{-2}\ K^4$

$R_1 = 0.08$ m

$R_2 = 0.09$ m

$\delta = 0.01$ m

FIG. 1 - DIAGRAMATIC REPRESENTATION OF THE PROBLEM.

5. METHOD OF SOLUTION

The governing differential equation can be given as [4,5],

$$\frac{\partial^2 T}{\partial r^2} + \frac{\Gamma}{r}\frac{\partial T}{\partial r} = \frac{1}{a}\frac{\partial T}{\partial t}, \qquad .. (1)$$

$$R_1 < r < R_2, \quad t > 0$$

where, $\Gamma = 0, 1$ and 2 for plane wall, cylindrical wall and spherical wall respectively. With inside boundary condition given by,

$$k \frac{\partial T}{\partial r} + h_g (T_g - T) = 0 \quad \text{at } r = R_1,\ t > 0 \qquad .. (2a)$$

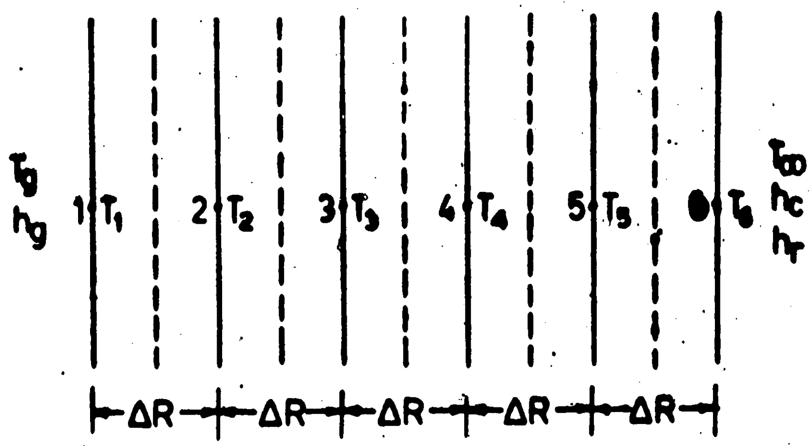


FIG. 2 - THE F.D. SCHEME ADOPTED FOR THE SOLUTION OF THE PROBLEM.

and outside boundary condition is given by,

$$-k\frac{\partial T}{\partial r} + h_c(T - T_\infty) + \sigma\epsilon(T_\infty^4 - T^4) = 0, \text{at } r = R_2,\ t > 0 \quad (2b)$$

The initial condition is given by, when $t = 0$;

$$T(r,0) = T_0 \quad ..(2c)$$

The problem has been taken up by subdividing the total wall into five equal subdivisions, and writing the heat balance equation for each layer as shown in figure (2). Thus, for inside boundary at point (1), the energy balance equation gives,

$$T_1^{j+1} = T_1^j\left[1-2F_0\left(1+B_g+\Gamma\frac{\Delta R}{2R_1}\right)\right] + 2F_0\left[\left(1+\Gamma\frac{\Delta R}{2R_1}\right)T_2^j + B_g T_g\right], \quad (3a)$$

For any intermediate points, the energy balance equation is given by,

$$T_n^{j+1} = T_n^j(1-2F_0)+F_0\left[\left(1+\Gamma\frac{\Delta R}{2R_n}\right)T_{n+1}^j + \left(1-\Gamma\frac{\Delta R}{2R_n}\right)T_{n-1}^j\right] \quad .. (3b)$$

where, $n = 2,3,4,5$

and for outside surface layer at point 6, the energy balance is given by,

$$T_6^{j+1} = T_6^j\left[1-2F_0\left(1+B_r+B_c-\Gamma\frac{\Delta R}{2R_6}\right)\right] + 2F_0\left[\left(1-\Gamma\frac{\Delta R}{2R_6}\right)T_5^j+(B_r+B_c)T_\infty\right], \quad (3c)$$

where, $B_g = h_g\delta/k$, $B_c = h_c\delta/k$. $h_r = \sigma\epsilon T_\infty^3(M+1)(M^2+1)$, is the equivalent radiative heat transfer coefficient, and $B_r = h_r\delta/k$ is the radiative Biot's number, $M = T_6/T_\infty$, $a = k/\rho c$ is the thermal diffusivity of material, and $F_0 = a\,t/\delta^2$ is the dimensionless time. The amount of heat needed for warming up of the wall at any instant of time is given by,

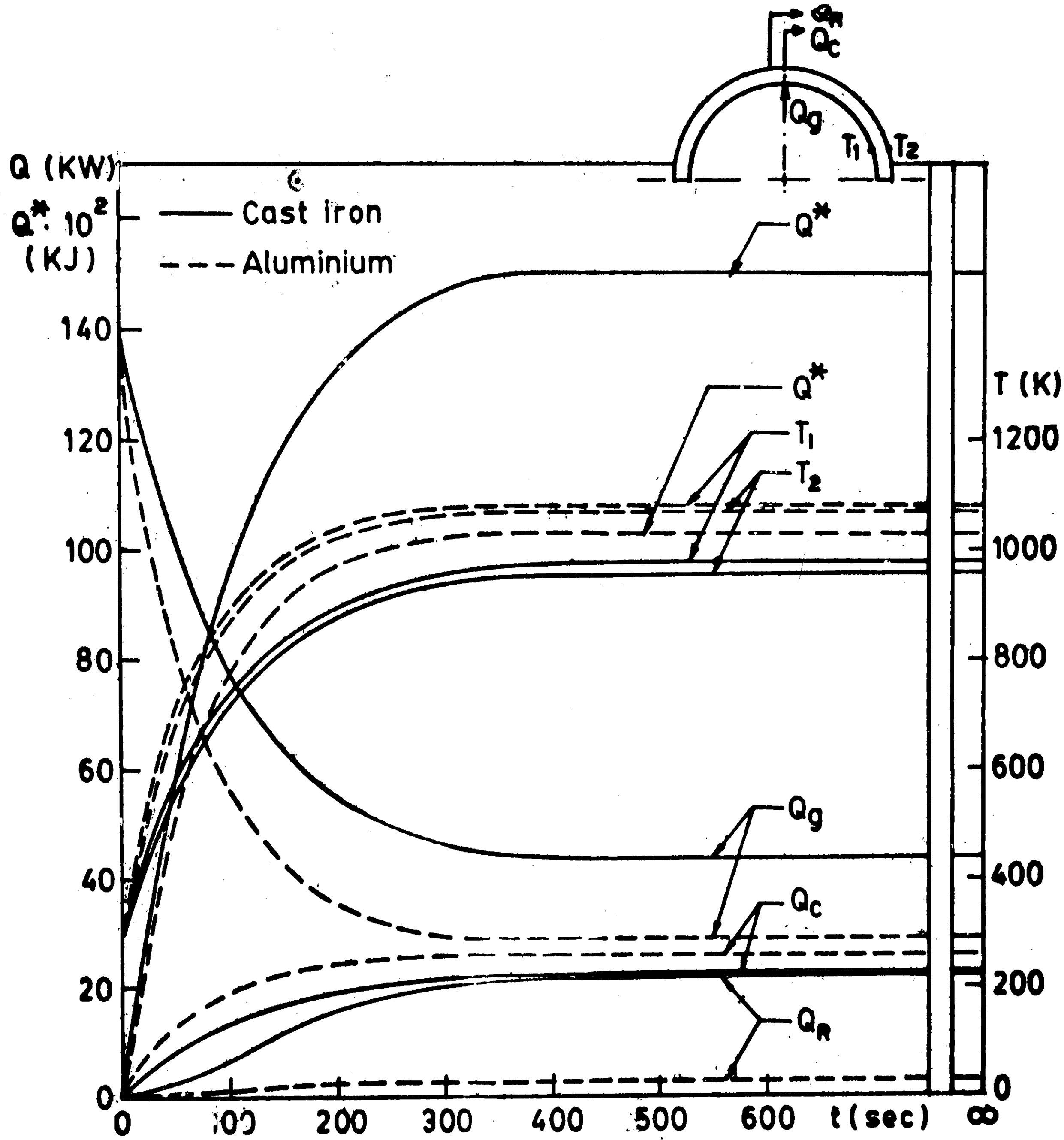


FIG. 3(a)- VARIATION OF TEMPERATURES AND HEAT FLOW RATES FOR CYLINDRICAL SHELL WITH TIME.

$$Q^{*}(t) = \sum_{i=1}^{i=6} \rho \; c \; \Delta v \; (T_i - T_0) \qquad .. (4)$$

where, Δ v is the volume of the element.

6. RESULTS AND DISCUSSIONS

Figures (3a, b, c) show variations of temperatures T_1 and $T_2 (=T_6)$ at inner and outer faces and of heat flow rates

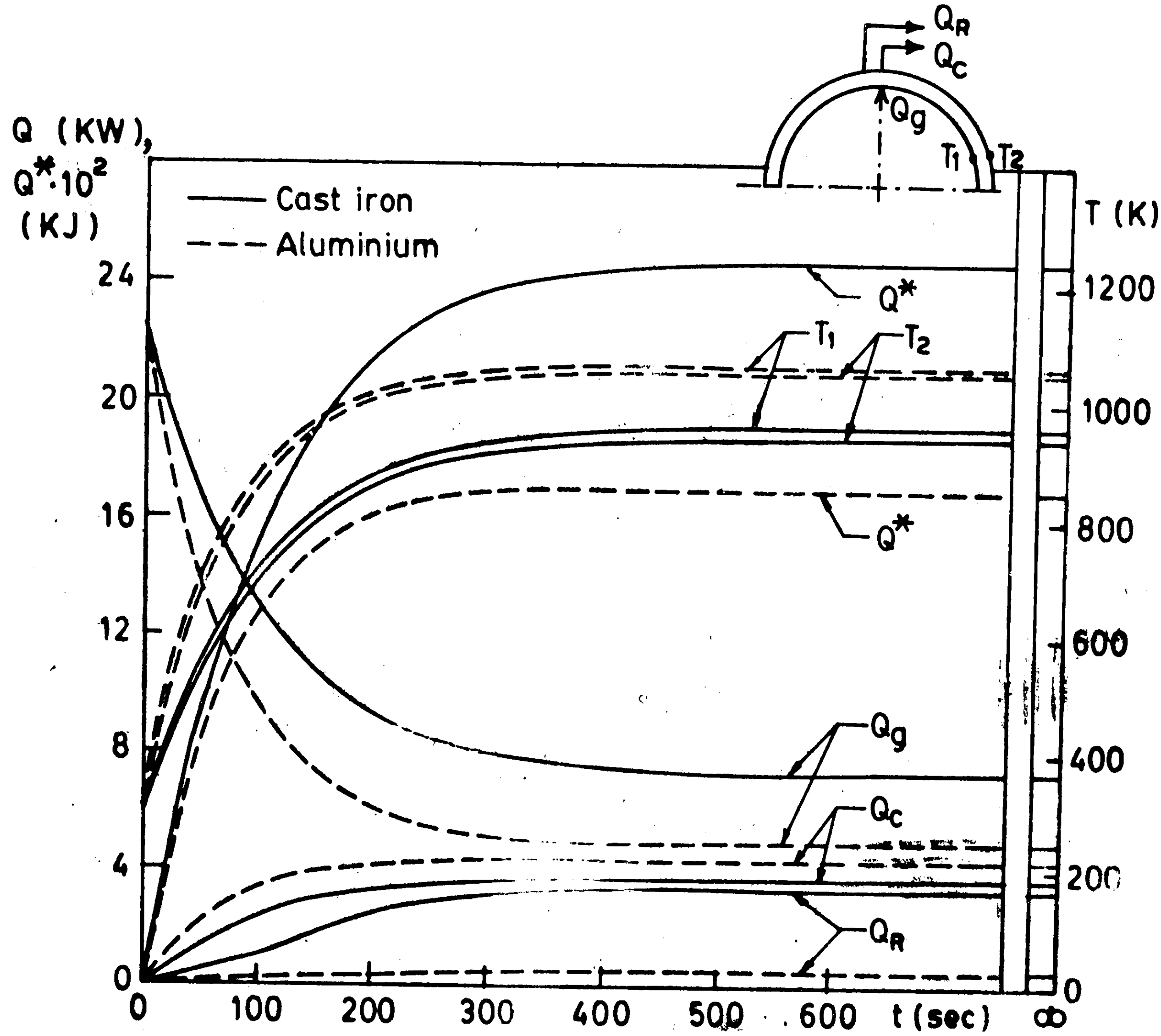


FIG.3(b)- VARIATION OF TEMPERATURES AND HEAT FLOW RATES FOR SPHERICAL SHELL WITH TIME.

Q_g, Q_c, Q_r with time for cylindrical, spherical and plane wall respectively. The times taken for attaining the steady state by aluminium plane wall, cylindrical and spherical walls are 900 secs, 935.5 secs and 949.5 secs while the times taken by cast iron plane wall, cylindrical and spherical walls of similar thickness are 1149.5 secs, 1205 secs and 1213.5 secs respectively. These results show that the cylinder wall warms up earlier than the spherical cylinder head of an internal combustion engine. The properties of the material influence the warming up period significantly.

The warming up periods of the plane, cylindrical and spherical walls are increased by approximately 4 minutes when wall material is changed from aluminium to cast iron. For the same

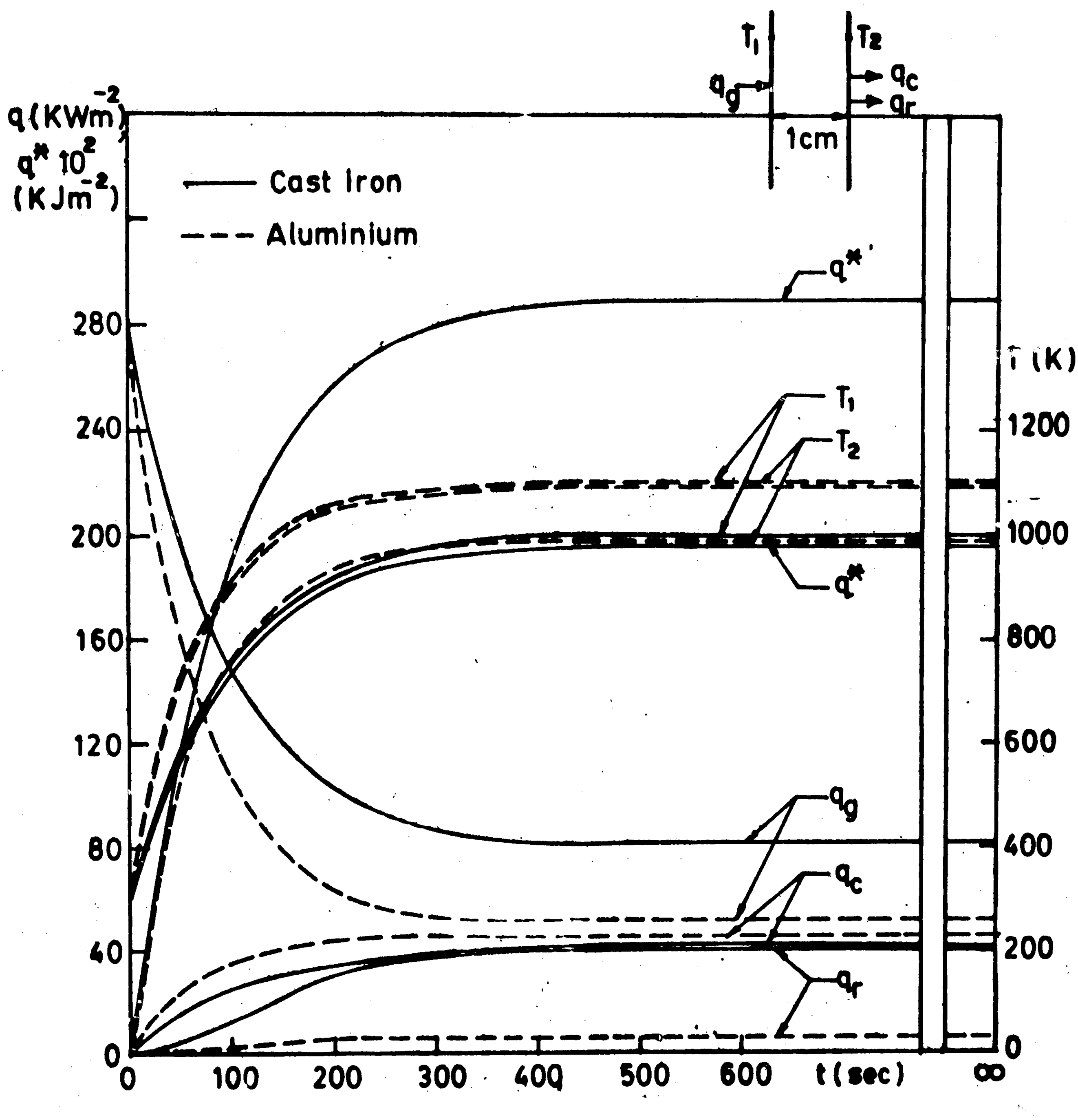


FIG. 3(c) – VARIATION OF TEMPERATURES AND HEAT FLUXES FOR PLANE WALL WITH TIME.

material, the warming up period increases appreciably when the shape of the wall is changed from plane to cylindrical or spherical but the increase in warming up period is very nominal when the shape is changed from cylindrical to spherical.

Under steady state condition, the heat loss due to radiation is in the range of 7.42 % to 8.2% for aluminium wall while it is in the range of 48 % to 52 % for cast iron wall. Such a wide difference between heat loss due to radiation in aluminium

and cast iron walls is due to very large difference in the emissivities of these materials (for aluminium, ϵ = 0.05 while for cast iron, ϵ = 0.80). The present analysis shows that mode of heat transfer for cast iron wall is dominated by radiation while for aluminium wall, it is dominated by natural convection.

Heat addition upto steady state by plane wall is 19828.23 KJ m^{-2} for aluminium and 29051 .763 KJ m^{-2} for cast iron. For Cylindrical wall, the heat addition is 10329.196 KJ for aluminium and 15052.965 KJ for cast iron, while for spherical wall, it is 1721.78 KJ for aluminium and 2488.87 KJ for cast iron. These results show that the cast iron wall offers more thermal capacitance than the aluminium wall during the process of warming up. The method of solution applied is finite difference technique for which the time step chosen is 0.0005 seconds gives sufficiently stable result.

Figures (3a,b,c) show variations of T_1, T_2 , Q_g , Q_c , Q_r, Q^* at any instant of time during the warming up process.

7. REFERENCES

[1] - Crosbie, A.L. and Viskanta, R., Int. J. Heat and Mass Transfer, 11, 305, 1968.

[2] - Davies, T.W., Transient conduction in a plate with counteracting convection and thermal radiation at the boundaries, Appl. Math. Modell. 9(5), 337, 1985.

[3] - Sunden, B., Transient heat conduction in a composite slab by a time -varying incident heat flux combined with convective and radiative cooling, Int. J. Heat and Mass Transfer 13 (5), pp. 515 - 522, 1986.

[4] - Myers, G.E., Analytical methods in conduction heat transfer McGraw - Hill, New York, 1971.

[5] - Ozisik, M.N., Heat conduction, pub. John Wiley and Sons, New York, 1980.

ترشيد استهلاك الطاقة (الكهربائية)
فى استعمال الاضـــاءة

أ. فتحى سالم ابوزخار .
أمين لجنة البحوث والاستشارات
فرع مركز بحوث العلوم الهندسية - هـــــــون
ص.ب - ٦١١٦٠ / هون - ليبيـــــــا .

1- ملخص البحث :

فى عالمنا المعاصر صار موضوع الطاقة يتصدر البنود الأولى من جداول أعمال الكثير من هيئات البحث العلمية ، وحيث أنه من اساسيات الانطلاق فى البحث والدراسه معرفة الدوافع ، لذلك سنورد لمحة عن اسباب دراسة قضية ترشيد استهلاك الطاقه عموما والطاقة الكهربائية المستعملة فى الاضاءة الصناعية خصوصا ، ثم نستعرض بعض الوسائل المساهمة فى الرفع من كفاءة الاضاءة الصناعية واستغلال الطاقة المستعملة لذلك الاستغلال الامثل وسنولى الطرق الاقتصادية فى استهلاك الطاقة المستعملة فى الاضاءة بعض التركيز ، بعد أن نعطى لمحة عن تاريخ استعمال الاضـاءة .

2- المقدمـــه :

رغم أن البحث عن بدائل الطاقة المستنفذة ، من العناوين البارزة التى تتصدر أفكار العلماء والبحاث والفلاسفة هذه الايام ، الا أن ذلك لا يقلل وينقص من أهمية دراســة ترشيد استهلاك ماتبقى عندنا من طاقة ناضبه فأستغلال الطاقة الاستغلال الامثل دون ، أن يكون هناك فقد أوهدر للطاقة هو ماسنركز عليه فى هذه الورقة عموما ، كما سنولى قــدر أكبر من الدراسة لترشيد الطاقة المستعملة فى الاضاءة .

وحيث أن مشاركة مصادر الطاقة الجديدة والمتجددة كطاقة الرياح وطاقة المد والجزر والطاقة الشمسية ، لن يتوقع لها أى دور فى الخليط الطاقى الا بحلول عام 2000 ولــن تكون لها اية تطبيقات محسوسة الا فى المجتمعات الريفية النامية [1] لذا سيكون مــن الغير معقول الا نعطى قضية الترشيد فى استهلاك الطاقة الناضبة - النفط والغاز - القدر الكافى من الدراسة والتمحيص ، والتى تمثل بالنسبة لنا احدى الموارد الرئيسية للدخــل القومى ، بالاضافة لكونها تستغل فى الطاقة ، والاضاءة ، والمواصلات ، وتوليد الطاقـــة الكهربائية .

ان قضية ترشيد استهلاك الطاقة المستعملة فى الاضاءة حسب وجهة نظرى ، قضية سلوك ووعى ، قبل أن تكون قضية هندسية ، فالذى يترك نور اضاءة مكتبة مفتوحا بعد انصرافه منه ، لا يمكننا أن ننعت ذلك التصرف الا بأنه انحراف فى السلوك، كما وأن عدم استعمال الالوان الفاتحة فى الطلاء ، لا تحتاج الا للتوعية فقط ولا تحتاج لتدريس الهندسة ومع ذلك، يتلخص توفير الطاقة المستعملة فى الاضاءة واستغلالها بكفاءة فى النقاط التالية [2] ، [3] .

أ) استعمال مصادر للاضاءة ذات فعالية وكفاءة عالية .
ب) استعمال المفاتيح - القواطع - المناسبة والكافية ، واستعمال المفاتيح ذات القدرة على خفض ورفع مستوى الاضاءة .
جـ) استغلال الاضاءة الطبيعية باستعمال الخلايا الضوئية .
د) تحديد برنامج ثابت للصيانة .

وبالطبع فأن الطريقة المثالية فى توفير الطاقه المستعملة فى الاضاءة هى استغلال الاضاءة الطبيعية ، وهذا لن يكون متوفر بالامكان دائما ، ولكن يبقى باستطاعتنا الاستفادة منها قدر الامكان . كما وأن هناك دراسة أظهرت نتائج ايجابية على انتاج الافراد فى اداء اعمالهم فى ضوء الشمس ، والسبب هو أن ضوء الشمس أكثر راحة للعين والجسم [4] ان استعمال الاضاءة الطبيعية هى الطريقة المثلى فى استعمال الاضاءة ، ولكن مع هذا نحن فى حاجة الى الاضاءة الكهربائية والتى تعتبر أفضل من غيرها من أنواع الاضاءة الصناعية فهى تتميز بأنها : أقل تكلفة ، وسهلة التحكم ، وأكثر نظافة ، وأقل مشاكل وحوادث ، ومساعدة فى زيادة الانتاج وذلك لانها أريح للعين اذا ما قورنت بغيرها من أنواع الاضاءة الصناعية . [5]

3 - لماذا ترشيد استهلاك الطاقة فى استعمال الاضاءة :

ربما نكون أكثر وضوحا اذا حاولنا أن نسأل أنفسنا لماذا ترشيد استهلاك الطاقة بدون أى تخصيص ثم ننتقل الى استعمال الاضاءة ولذا سيكون العنوان الفرعى القادم :

3.1 لماذا ترشيد استهلاك الطاقة؟

لقد ولى زمن (الوفرة فى المواد الاستهلاكية) وحل محله زمن (الندرة والضوابط الاقتصادية) الذى لم يعد بوسع الانسان فى ظله أن يستمر فى استهلاك كل مايشاء من الغذاء والطاقة والمياه والمواد المختلفة دون حدود ، فقد اخذت الطبيعة تتململ من بذخ الانسان واسرافه ، وتضيق بتدخلاته فى النظام البيئى وانهاكه موارد الارض [6] هذه كانت بداية لعرض وتحليل الاستاذ / ياسر فهد . لكتاب الطاقة والاقتصاد والبيئة للاستاذ / هرمان دالى "Herman E.Daly" استاذ الاقتصاد بجامعة لوزيانا ، والاستاذ / الفارو اومانا "Alvaro Umana" استاذ الهندسة البيئية فى جامعة كوستاريكا . فى هذا العرض مؤشر بمدى اهمية ترشيد استهلاك الطاقة واعتبارها قضية ملحة ومهمة لكى يتحاوز فيها الجميع .

ان قضية توفير الطاقة أو بالاحرى ترشيد استهلاكها كانت هاجس الكثير من الشركات البريطانية وقد توصلت الكثير من شركات التصنيع الى القناعة بتوقيع عقود مع شركات تتولى

المسؤلية الكاملة فى تشغيل ادارة الطاقة ،لكافة المرافق الخدمية بها ، مثل الشركات التى تختص بالتنظيف ،وهنا يصرح السيد / بيتروا كر "Peter Walker" أمين الطاقة ببريطانيا . "ان بأمكانية مصانع بريطانيا توفير ما قيمته 7000 مليون جنيه استرلينى من خلال برنامج ادارة الطاقة" [7] .

وحيث اننا بصدد الطاقة الكهربائية ،لانها تكاد ان تكون الان الطاقة الوحيدة المستعملة فى الاضاءة ،فتحدر الاشارة الى ان النمو فى الاحمال الكهربائية خلال السنوات القادمة سوف لن يقابله زياده مماثلة فى القدرات الكهربائية وذلك نتيجة لدخول المحطات الجارى تنفيذها مرحلة التشغيل وتأجيل التعاقد على تنفيذ قدرات جديدة الامر الذى يؤدى معه الى الى اختلال التوازن فى ميزانية الطاقة خلال السنوات القادمة مما سيتطلب الامر التركيز على رفع كفاءة الصيانة فى القدرات المركبة [8] والرفع من مستوى الترشيد فى استهلاك الطاقة واستغلالها بكفاءة عالية ،بحيث لا تهدر بدون مقابل ويبقى الاستهلاك حسب الطلب ،وبالقاء نظره على زيادة استهلاك الطاقة خلال الاثنى عشرة سنة الماضية نجدانها قد تضاعفت الى ستة عشر "16" مرة بالنسبة للاستهلاك المنزلى والانارة العامة واحدى عشرة "11" مرة بالنسبة للاستهلاك الصناعى، اما بالنسبة للاستهلاك الزراعى فقد تضاعف مرة ونصف" 1.5" أنظر الشكل رقم (1)* وبقدر هذه الزيادة المتضاعفة فى الاستهلاك يجب أن يقابلها أيضا زيادة فى الحرص على ترشيد الاستهلاك ومن هنا نصل الى حتمية الترشيد فى استهلاك الطاقة.كما يجب ان نعى أن من حق الاجيال القادمة من أن تشاركنا فيما نملك من طاقة ولو بجزء بسيط ولن يكون لها الفرصة فى ذلك اذا مارمينا بما عندنا من طاقة فى محارق اللامبالاة .

من وسائل ترشيد استهلاك الطاقة استعمال الاحمال الاكثر كفاءة وتقليل نسبة الضياع فى الطاقة المفقودة والدراسات تقول بأن توفير كيلو واط من الطاقة المفقودة "losses" سيعوض مابين ثلاثة الى ستة 3 - 6 كيلو واط من طاقة الوقود ، [9] ، [10] . وبتوفير كيلو واط ساعة من الطاقة المفقودة فى الحمل سيوفر لنا أربعة ونصف 4.5 اذا ما اخذنا متوسط 3 الى 6 - كيلو واط ساعة من الوقود .

3.2 لماذا الترشيد فى استعمال الاضاءة :

ربما يتساءل الانسان ،لماذا نولى أهمية لدراسة استهلاك الطاقة فى استعمال الاضاءة ،وهنا نورد بعض ما يؤكد أهمية هذه الدراسة ففى بريطانيا ما بينته الاحصائيات بأن الحكومة يمكنها توفير ما قيمته 150 مليون جنيه استرلينى سنويا ،اذا ما استعملت الاضاءة فى المصانع والمدارس والمحلات التجارية بصورة أكثر كفاءه وفعالية [11] .

كذلك يورد الاستاذ / كرت ريجل "Kurt W. Riegel" والذى يشغل منصب رئيس المعدات والتنقية فى ادارة بحث الطاقة والتنمية (ERDA) فى واشنطن دى سى فى مقاله،" ان الاضاءة لها أهمية عظمى بالنسبة لبرنامجنا فى ادارة بحث الطاقة والتنمية وفى ملخص ما وصل اليه يقول " ان استهلاك الاضاءة للطاقة يمثل 5 - 6 % من الاستهلاك القومى للطاقة و 20 - 25 % من استهلاك الطاقة الكهربائية بامريكا [12] " وان كنا موافقين على اهمية ترشيد استهلاك الطاقة فى استعمال الاضاءة ،الا اننا نجد أنفسنا أمام من له وجهة نظر أخرى كالسيد / هارود براندستون " H. Brandston " والذى

* انظر الصفحة رقم ((10)) .

يقـــول "اذا استطعنا ان نخفض من استهلاكنا للطاقة بنسبة 15% نستطيع أن نمد سنتين فى عمر مصادر الطاقة الناضبة للطاقة قبل أن تستنفذ عام 1990 م، وهذا التخفيض سيرفع من نسبة العاطلين عن العمل وسيفسد ويحد من النمو الاقتصادى فالاضاءة والتى تشكل نسبة 5 - 6 % من الطاقة الكلية (يتسأل بالنفى) هل يمكن بتنظيم استهلاك الطاقة للاضاءة أن يكون هناك اسهام ملحوظ [13] ؟ ربما يكون من الصعب فهم كيف ربط الاستاذ / براندستون بين خفض استهلاك الطاقة المستعملة فى الاضاءة والتدمير الاقتصادى وزيادة العاطلين رغم أن هذا ماسيزيد من رفع المستوى الاقتصادى واذا كنا مترشدين فى استهلاكنا للطاقة، سنمد فى عمر الطاقة لاستغلالها فى التصنيع وما الى ذلك .

يقول الاستاذ / براندستون " يجب أن نتذكر بأننا نصمم ونهندس بقصد الاضاءة للبشر وليس لاجهزة قياس الاضاءة فهذه الاجهزة لا تشغل ولا تعمل فى الاماكن التى نصمم لها الاضاءة " [13]. وهنا يتضح بعض ماكان يقصده فى البداية وان كنا نتفق معه فى كلامه الاخير، الا اننا مازلنا نرى ان قضية الترشيد فى استهلاك الطاقة المستعملة فى الاضاءة، هى قضية سلوك وخلق يجب ان يتخلق به كل مهندس، وموظف، بل وكل مواطن ومواطنة .

كذلك من دواعى النظر فى استهلاك الطاقة المستعملة فى الاضاءة انها تمثل 30-50% من نسبة تكلفة تشغيل المبانى [14] ومن هنا نستطيع ان ننتقل الى كيفية ترشيد استهلاك الطاقة فى استعمال الاضاءة، وسنبدأ بأختيار المصابيح وعلاقتها بالكفاءة والفعالية بعد أن نأخذ نبذة عن تاريخ استعمال الاضاءة .

4- الاضاءة من الوجهة التاريخية :

بدأ الانسان منذ القدم باستغلال موارد الطاقة الطبيعية من خشب وحطب فى الاضاءة كاستعماله لها فى الطهى والتدفئة وحماية نفسه وأخذ الانسان فى تطويره لوسائل استعمال الاضاءة فأستعمل الزيت ومقطرات الفحم والشمع من بعد، ومع بداية اكتشاف النفط والتعرف عليه فى سنة 1848 م تمكن العالم الكيميائى جيمس ينغ "James Young" من تقطير النفط ليحصل على مادة خفيفة أستعملت فى اضاءة المصابيح سميت المادة بزيت الاضاءة " Illuminating oil " والتى تدعى حاليا بالكيروسين [15] وبذلك استبدل النفط كطاقة فى استعمال الاضاءة .

بدأت اول ومضة لانارة تاريخ الاضاءة الكهربائية، بعد اعلان العالم فولتا "Volta" عن اكتشافه للتيار الكهربائى فى سنة 1800 م، وفى سنة 1802 كانت ملاحظة العالم همفرى ديفى " Humphry Davy" للدفق الساطع " Arc" الناتج من مرور تيار كهربائى خلال قطعة كربون مكسورة [16] ومن هنا كان الوصول الى اختراع مصباح الدفق الساطع "Arc lamp" سنة 1808 م . [18]

وان كانت حلقات الاكتشاف متصلة، الا ان أكتشاف مصباح الدفق الساطع لم يكن العامل الاساسى فى اكتشاف مصباح التوهج "Incandescent lamp" ففى سنة 1867 م كان اكتشاف ورنر سيمنس " Werner Siemens" للمولد الكهربائى - ذاتى التهيج - والذى اسهم أسهاما مباشرا فى اختراع مصباح التوهج . [17]

لقد أستعرض سوان اختراعه ـ مصباح التوهج ـ فى ديسمبر 187 م بنيوكاســـل " New Castle " ببريطانيا وبعده بعشرة أشهر قدم العالم أيديسون " Edison " مصباحه الكهربائى فى 19/ أكتوبـر / 1879م . بالولايات المتحدة الامريكية ولم يتمكنــا العالمين من بيع أختراعهما الا بعد صيف 1880م . [17] وبعد ذلك بأربع سنـــوات سنة 1884م ـ بدأ التعرف على مصابيح التوهج الغازية "Incandescent-gas " [18].

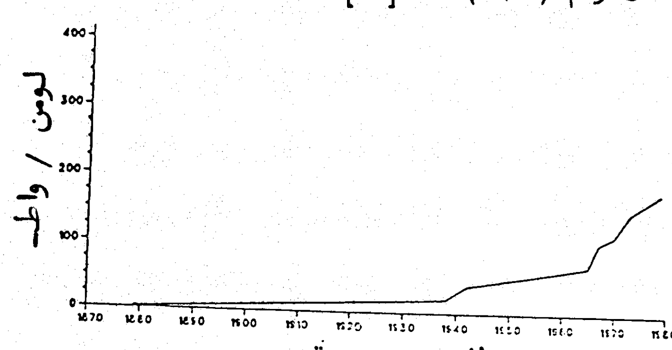
تميزت مصابيح التوهج الكهربائية بثلاثة ميزات عن مصابيح الدفق الساطع وهــــى كما يلـــــى : [17،18] .

أ) تعطى اضاءة تمتاز بالاستقــــرار .
ب) لا تحتاج للمتابعة والملاحظـــــة .
جـ) يمكنها ان تكون فى احجام صغيره .

قبل بداية الحرب العالمية الثانية بدأت مصابيح التفريغ الغازية " Gas-discharge " تحتل مكانة كبيرة بين المصابيح المستعملة أن ذاك ،وذلك لكفاءاتها العالية ومع ذلك لم تأخذ مكانها الطبيعى الا مع سنة 1930 م ،رغم أن مصنع فان امبدن " Van Embden " بأمستردام ،قد بداء بأستعمال مصابيح التفريغ سنة 1901م . [18]

5 ـ كفاءه وفعالية مصادر الاضاءة :

بالنظر الى الشكل رقم (2) يتضح لنا أن فعالية المصابيح الكهربائية قـــــد تطورت من تاريخ اكتشافها الى السنوات الاخيرة ،وقد وصلت الى 180 لو من للـــواط بعد أن بداءت بـ 1.4 لو من للواط [19]. وبالرغم من هذا التطور ،الا اننا نجدانفسنا لم نستغل هذا التطور ،فأكثر المصابيح شيوعا عندنا هى مصابيح التوهج ومصابيـــــح الفلورسنت ،رغم أن كفاءتها لا تعتبر عالية اذا ما قورنت بغيرها ،ويتضح لنا ذلـــــك بكل جليه اذا نظرنا للشكل رقم (3) . [20]



الشكل رقم (2) التطوير فى فعالية المصابيح الكهربائيـة

كما وأن الاستبيانات السبعة ـ من بين التعميم الذى قام به الكاتب العام لأ مانـــة الصناعة على جميع المصانع ونحن شاكرين له هذا الجهد الطيب ـ التى وردت الينـــا تؤكد لنا ان المصابيح المستعملة أما مصابيح التوهج او الفلورسنت ،وتجدر الاشارة هنا الى ضرورة توفير المصابيح ذات الكفاءة العالية أولا فى السوق قبل أن نتكلم على مـــدى

أسهـــام فعالية المصابيح في توفير الطاقة وترشيد استهلاكها .

6- الغرض من استعمال الاضــاءة :

بعد الالمام بكفاءة المصابيح وعلاقتها بتوفير الطاقة ننتقل الى الغرض من استعمال الاضاءة ، والذى بدوره سيساعدنا فى تقرير قوة وعدد المصابيح المطلوبة وهنا تأتـــى ضرورة معرفة نوعية المعمل وطبيعته [5] فمعرفة الغرض من الاضاءة بطريقة صحيحـــة يعتبر من الطرق المساهمة فى توفير الطاقة [14] كما وأن معرفة طبيعة المكان نفســه تساعد فى تقرير قوة وعدد المصابيح المراد استعمالها ، ومن ذلك نخلص الى أن تركيز الاضاءة يكون فى الجهة التى تحتم طبيعة العمل فيها ذلك بدون بعثرتها بدون فائدة ويمكننا أن نلخص اماكن العمل فى ثلاثة انواع

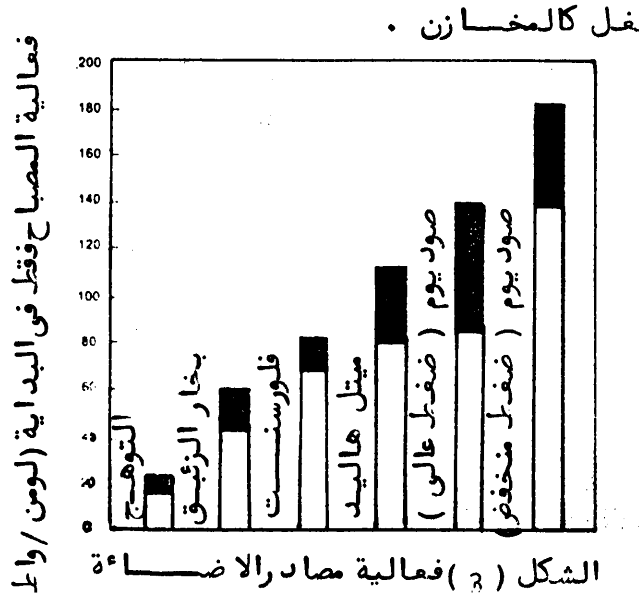
أ) اماكن مشغولة تحتاج للاضاءة لكى :

1- تقلل من مشكلة النظر وتساعد على النظر بدون صعوبة .

2 - التحرك من جهة لاخرى .

ب) اماكن غير مشغولة ، وهى للحركة فقط مثل الممرات وهى تحتاج لاضاءة تمكن مـــن الحركـــــة .

جـ) اماكن قليل ماتشغل كالمخــازن .



الشكل (3) فعالية مصادر الاضــاءة

بمعرفة طبيعة المكان والدور الذى سيقوم به المصباح ، يترتب عليه تحديد قـــوة المصباح وهذا يلعب دورا كبيرا فى توفير الطاقة ، فعلى سبيل المثال - قوة المصبـــاح التى نحتاجها لحجرة المذاكرة ستختلف على قوة المصباح التى سنحتاجها للممرات واذا بالخطاء جعلنا قوة مصباح الممر 100 واط بدل من 40 واط وكان بالممر مصباحـــين عندها اذا افترضنا عدد ساعات استعمال الاضاءة بالنسبة للممر عشرة ساعات يوميـــا يكون مقدار المصروف فى الطاقة سنويا : 7300 = 365 x 10 x 100 x 2 كيلو واط ساعة سنويـــا .

اما اذا إستعملنا مصابيح قوتها 40 واط يكون مصروف الطاقة سنويا : 2 x 40 x 10 x 365 = 292 كيلو واط ساعة سنويـــا .

وتكـــــون قيمة الطاقة الموفرة بالدنانير فى السنـــــة :

$$(730 - 292) \times \frac{2}{100} = 8.76$$ دينار سنويـــا .

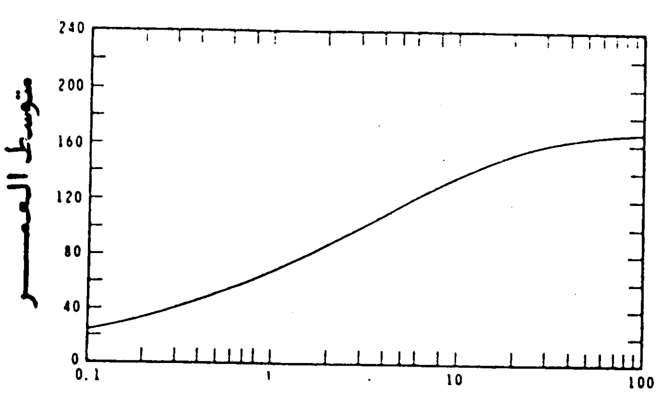
واذا طبقنا ذلك على احمال الوحدات السكنية للخطة الاسكانية 81 / 85 مـــــم والبالغ عددها 206143 وحده سكنية [21] سيكون المبلغ الموفر حوالى مليونى دينـــار سنويـــــا .

$206143 \times 8.76 = 1805812.68$ د.ك.

7 - المفاتيح (القواطع) ودورها فى ترشيد استهلاك الاضاءه :

بعد التعرف على طبيعة المكان ونوعية العمل المطلوب أداءه ،بقى ان نتعرف على طرق فصل الاضاءة فوجود قواطع - مفاتيح - الاضاءه فى متناول ايدى الموظفين يعـــنى ذلك خفض استهلاك الكهرباء فى كثير من الحالات [22] وقد اجريت دراسه للطابـــق الخامس بمبنى جين مانس "Janne Mance" بمدينة اتوا " Ottawa " فى محاولـــة لتخفيض استهلاك الطاقة المستعملة فى الاضاءة فبعد أن كان الطابق موصول بمفتـــاح رئيسى مركزى يفتح ويفصل الاضاءة عند بداية ونهاية الدوام فقد تم توصيل جميع المكاتب الخاصة بمفاتيح يدوية وكذلك الممرات وقاعات الاستقبال والمكاتب المفتوحة والحقـــت بمفتاح أوتماتيكى يفصل الكهرباء فى نهاية الدوام عن الممرات وقاعات الاستقبال والمكاتب المفتوحة . ربما تأخذ بعض الوقت ليتدرب الموظفون على فصل الكهرباء عن الاضاءه اذا لم يتعودوا على ذلك من قبل ،ولكن فى النهاية اثبتت الدراسة أن استهلاك الطاقـــة قد انخفض الى 40 % وفى خاتمة هذه الدراسة تبين أن المكتب الذى يشغله أكثر مـــن شخص واحد يكون من الصعب فى ذلك الوقت الالتزام بغلق مفاتيح الاضاءة عند تـــرك المكتب [23].

وهنا تجدر الاشارة بأن العلاقة بين عدد مرات استعمال مصابيح الفلورسنـــــت عكسية مع عمر المصباح - هذا لا ينطبق على مصابيح التوهج - انظر الشكل رقـــم (4)



الشكل رقم (4) : أثر دورات التوهج علـــى متوسط عمر أكثر مصابيح الفلورسنت شيوعـــا

وهذه العلاقة غير صحيحة مع ثقل الموازنة " Ballast " [24] اذ أن الغـــرض

من التنويه هنا هو عدم سوء استعمال مصابيح الفلورسنت بالفتح والغلق بدون سبب فنحن مازلنا نؤكد على قفل الاضاءة عند عدم الحاجة اليها ،ربما اذا حاولنا ايصال مفاتيح يدوية للاضاءة لمجموعة من المكاتب موصولة بمفتاح رئيسي للاضاءة ،نتوقع بأن العملية ستكون عملية غير اقتصادية ،هنا يمكننا متابعة المثال الاتي لاثبات عكس ذلك : [14]

عدد المكاتب "سته"	الحالة الاولى	الحالة الثانية
طريقة توصيل المفاتيح	مفتاح مركزى	ستة مفاتيح لكل مكتب
تكلفة تركيب المفتاح*	5.80 دينار	34.8 دينار
عدد المصابيح	اثنى عشر مصباح (2 × 6)	اثنى عشر مصباح (2 × 6)
قوة المصباح	100 واط	100 واط
عدد ساعات العمل يوميا**	8 ساعات	5 ساعات
عدد ايام العمل فى السنه	317	317
كيلو واط لكل ساعة	3043.200	1902
التوفير فى الطاقة		1141.2 كيلو واط ساعة
التوفير فى الفاتورة		22.82 دينار
الفرق فى توصيل المفاتيح		34.8 - 5.80 = 29 دينار

يلاحظ أن فى خلال سنة وبضعة اشهر يمكن تغطية تكالفية المفاتيح المضافة لكل مكتب ،ومن بعد ذلك سيوفر 1141.2 واط سنويا .

8 - علاقة الصيانة بترشيد استهلاك الطاقة :

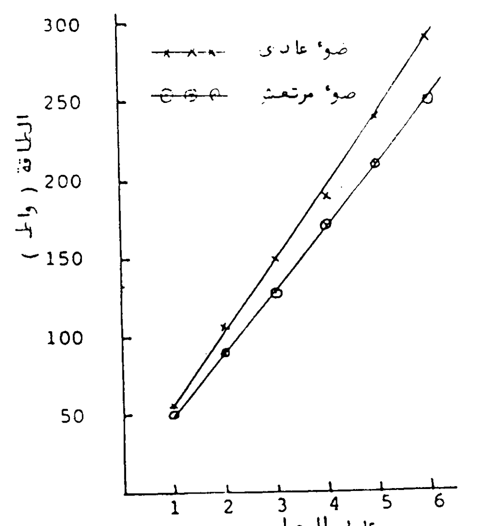
بمعرفة مدى فعالية المصابيح وكفاءتها ،والغرض من استعمالها فى الاضاءة كذلك بمعرفة طريقة وصل وفصل المصابيح بالكهرباء وعلاقتها بأستهلاك الطاقة ،بقى علينا أن ، نعرف أيضا أن من احدى الوسائل التى تسهم فى ترشيد استهلاك الطاقة عموما والطاقة المستعملة فى الاضاءة خصوصا الصيانة لما تلعبه من دور فى التخفيض من الطاقة المفقودة " Losses " فعدم وجود صيانة جيدة لانظمة الاضاءة مدعاة لهدر الطاقة فالكثير من المؤسسات والجمعيات التجارية تدفع فواتير الكهرباء (ربما يوجد عندنا بعض التقاعس والتسيب فى الدفع) بدون أن يتحصلوا على القدر المناسب من الاضاءة (الفيض الضوئى) . ومن العوامل الرئيسية فى هبوط مستوى الاضاءة أو الفيض الضوئى مايعلق [25]

* تكلفة تركيب المفتاح ،أعتبرت 0.35 دينار ثمن المفتاح 0.45 دينار ثمن 4 امتار من السلك ،و 5 دينار تكلفة التركيب ،مع الملاحظة بأن الاسعار أخذت من السوق العام بالنسبة للمفتاح والسلك .

** على اعتبار انها ساعات التواجد بالمكتب وترك الاضاءة فيها مفتوحه .

بالمصابيح من أتربة وغبار . [5] فلذا يكون من الضرورى وجود برنامج لصيانة وتنظيف المصابيح وملحقاتها من عواكس وغيرها . كما وأن بعض المصابيح بعد فترة من الاستعمال ينخفض فيها الفيض الضوئى وعندها لا تكون أقتصادية ويبقى من الضرورى تغييرها ولن يحصل ذلك الا بوجود برنامج صيانة ثابت .

ويتضح لنا بتجربة بسيطه أنه بعدم وجود برنامج للصيانة ،يدفعنا لاستهلاك الطاقة مقابل الضرر بأنفسنا ،فعندما نهمل تغير مصابيح الفلورسنت ذات الضوء المرتعش ،فأن ذلك سيضر بأعيننا . وبايجاد علاقة بين الطاقة المستهلكة لعدد من مصابيح الفلورسنت التى تصدر اضاءة معتدلة وأخرى تصدر اضاءة مرتعشة نجد أن مقدار الطاقة المستهلكة فى الحالتين متقارب ،أنظر الشكل رقم (5) ومن هنا نلخص مدى أهمية الصيانة وضرورتها.



الشكل رقم (5) العلاقة بين عدد مصابيح الفلورسنت ذات الضوء المرتعش والعادى - والطاقة .

9- التوصيات :

1 - بالنسبة لتوفير الطاقة عموما نوصى بأن تفتح اقسام متخصصة بمتابعة استهلاك الطاقة فى جميع المؤسسات والمصانع ،ويمكن أن تسند هذه المهمة لاقسام الصيانة

2 - لكى نتحصل على متخصصين فى مجال الطاقة ،يجب أن تفتح معاهد متخصصة لذلك

3 - أن التشديد على جميع المؤسسات بدفع فواتير الكهرباء سيساعد بأتخاذ اجراءات سريعة بخفض الاستهلاك ،وهذا ينطبق حتى على المواطن .

4 - تحديد مواصفات خاصة فى البناء ،تمكن من استغلال الاضاءة الطبيعية ،بحيث لا يعتمد أى تصميم يخرج عن هذه المواصفات ،واعتبار ذلك مخالف للقانون .

5 - توفير المصابيح ذات الكفاءة العالية ،والحث على استعمالها وخاصة بالمصانع والانارة العامة .

6- التأكيد على وجود فواصل للاضاءة بكل مكتب ،وتوعية الموظفين بعدم ترك الاضاءة عند تركهم لمكاتبهم ،ويكون ذلك بتعميم مناشير بالخصوص من جهات الاختصاص.

7- التأكيد على وجود برامج توعية للمواطنين من خلال الاذاعتين المرئية والمسموعة ترشدهم في صرف الطاقة ،واستعمال الاضاءة .

8- التأكيد على وجود برامج لصيانة وتنظيف المصابيح وملحقاتها ،على ألا تتعدى مرة كل ستة أشهر .

ولا يسعنا في الختام الا ان نقول كما قال سقراط " كلما أزددنا كمالا قلت حاجاتنا (وسيقل صرفنا وتبذيرنا للطاقة والاضاءة) وكلما قلت حاجاتنا أقتربنا من الكمال" .

10 - المراجع العربية والاجنبيــة :

[1] د . عبدالحي بن عمران "استراتيجية الاستعاضة عن النفط قبل عصر مابعد النفط" الثقافة العربية - العدد 8 - السنة الثانية عشر - ص 38 - 1985 م .

[4] الدكتورة . أمل على المخزومي "الضوء وسلوك الانسان" العربي ،العدد 345 . ص 109 - أغسطس 1987 م .

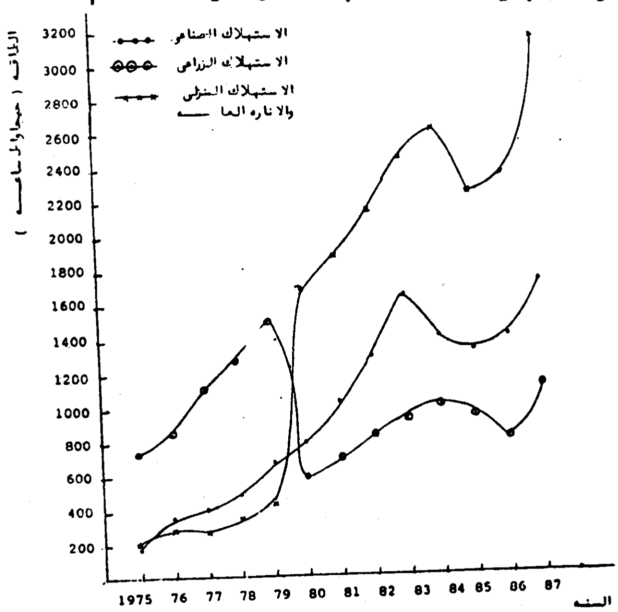
[5] أ . فتحي سالم ابوزخار . "اضاءة المصانع علاقة مباشرة بالانتاج" مجلة المهندس - تحت النشر .

[6] ياسر الفهد . عرض وتحليل كتاب : "الطاقة والاقتصاد والبيئة" العربي - العدد 328 - ص 183 - ص 187 - مارس 1986 م .

[8] . مؤسسة الكهرباء " تقرير متابعة ميزانية التحول لسنة 1987 م - 1988 م " .

[15] الدكتور . عبدالاله مصلح التكريتي "بدائل الطاقة حاضرا ومستقبلا" العربي - العدد 300 ،ص 107 ،نوفمبر 1983 م .

[25] . نشاط أمانة الاسكان والاجهزة التابعة لها ،نوفمبر 1982م .



الشكل رقم (1) أستهلاك الطاقة الساعه على مدى الأثنى عشره سنه الماضيه

[2] Ssavvides, Teng Mielecie., " Energy-efficient, Lighting achieves big saving", Electrotechnology, p.p. 57-60, April 1986.

[3] Corwin A. Bennett, " Handbook of Industrial Engineering", Chapter 6.11, A Wiley-Interscience Publication John Wiley & Sons, 1982.

[7] Peter Walker, "Saving money by letting Others manage energy", Electrical Review, Vol. 217 No.2, page 27-28, August 1985.

[9] William J. McDonald, and Herbert N. Hickok, "Energy Losses in Electrical Power System", IEEE Transactions on Industry Application Vol. IA21, No. 4, p.p. 803, May/June, 1985.

[10] Herbert N. Hickok, " Adjustable speed - A Tool for saving energy losses in Pumps, Fans, Blower, and Compressor", IEEE Transactions on Industry Applications, Vol. IA-21, No.1, p.p.124, January/February.

[11] Pallab Ghosh, " If the light is right, you've on to a winner", Electrical Review, Vol. 216 No. 12 page 20-22, 12 April 1985.

[12] Kurt, W. Riegel, " Lighting and energy-a federal perspective", Lighting Design & Application, page 9-10, January 1976.

[13] Howard Brandston, Iald, Mies, " What environmental price do we pay to conserve energy?", Lighting Design & Application, page 35-37, August 1981.

[14] Ronald N. Helins, " Illumination engineering for energy efficient luminous environments", Chapter 8, Prentic-Hall, Inc., Englewood Cliffs, 1980.

[16] Percy Dunsheath, " A History of Electrical Engineering", Chapter VIII, page 123, 133-134, 137 Western Printing Services Limited, Bristol, 1962.

[17] C.N. Brown, " Early days of electrical lighting", IEE Review, page 223-225, June 1988.

[18] H. Zijl, " Illuminating Engineering Course", Chapter 13, page 92-95. The Philips Technical Library 1955.

[19] Clark. W. Gellings, " Load Management, Lighting Codes, Energy and pumpkins", Lighting Design & Application , p.p. 34-36, February 1983.

[20] Aurele J. Maillet, " Current lighting Practice Trends for pulb and Paper Industry", IEE Transactions on Industry Applications Vol. IA-21, No.2, p.p. 362-374, March/April 1985.

[22] F. Rubinstein, M. Kavayel and R. Venderber, " Field Study on Occupancy Scheduling as a Lighting Management, Lighting design & Application, p.p. 34-38 May 1984.

[23] W. Robertson, " Light Switching for Energy Conservation in an Office Environment", Lighting Design & Application p.p.35-40, February 1984.

[24] Louis A. Carriera & Mark S. Rea, " Economics of Switching,Fluorescent lamps", IEEE Transactions on Industry Applications,Vol. 24, No.3, p.p. 370-378, May/June 1988.

[25] Ken Attenbury, " Lighting maintenance-how realistic is the payoff", Electrical Review, Vol. 217, No. 12, p.p. 47-48, November 1985.

GOAL PROGRAMMING APPROACH TO POWER SYSTEM OPTIMIZATION PROBLEMS

K.G. Laxmi, Arizona State University,
Tempe, Arizona, U.S.A.

N. Srinivasan*, Electrical Engineering
Research Unit, Garyounis University,
Benghazi, Libya.

K. Mallikarjuna Chetty,
P. Narayana Reddy,
S. Laxman Reddy,
Department of Electrical Engineering,
U.V.C.E., Bangalore-560 001,
INDIA.

1. ABSTRACT

Some of the important problems concerning power system planning and operation have been solved by mathematical optimization methods. Minimization of generation costs and minimization of transmission losses are two such important factors which in turn reduce the total operating costs of a power system.

The generation costs and transmission losses in a power system are normally nonlinear functions subject to the condition that the load flow equations are satisfied. These load flow equations are themselves nonlinear equations with limits imposed on active and reactive power generations as well as on voltage magnitudes and bus angles.

In the method proposed, generation costs and transmission loss function are linearized first and minimization of these two is considered as two separate objective functions of a multiple objective optimization problem. The linearized load flow equations, limits imposed on voltage magnitudes and bus angles form constraint equations. As a first approximation, no limits are imposed on active and reactive power generations. The mathematical model so developed is solved by Goal Programming Approach in case of a typical 5-bus, 7-line, 3-generator power system setting a higher priority to the minimization of generation costs.

2. INTRODUCTION

Many important power system operation and planning problems like economic dispatch, hydro-thermal unit commitment, generation, transmission and distribution planning, reactive power scheduling and allocation etc. have been viewed as mathematical optimization problems. Linear, quadratic, integer, dynamic programming procedures, other nonlinear

*Address for communication.

programming techniques and their variations have been successfully used to solve many of the above mentioned problems [1-6].

In this paper, goal programming approach is developed to solve the multiple objective optimization problem associated with 'minimization of generation costs' and 'minimization of transmission losses' of a power system as two goals or objective functions. The linearized version of load flow equations and limits imposed on bus voltages and bus angles form the constraint equations.

The model developed is applied in case of a typical 5-bus, 3-generator, 7-line power system and the results obtained by this computer-simulated model are shown at the end and the relevant conclusions are drawn.

3. MODEL

Minimize:

$$f_1 = \sum_{i=1}^{N_g} C_{0i} + C_{1i} P_{Gi} + C_{2i} P_{Gi}^2 \tag{1}$$

(cost of real power generation)

$$f_2 = \sum_{i=1}^{N} (P_{Gi} - P_{Di}) \tag{2}$$

(transmission losses)

subject to

$$P_i = P_{Gi} - P_{Di}$$

$$= V_i \sum_{j=1}^{N} V_j[G_{ij} \cos(\delta_i-\delta_j) + B_{ij} \sin(\delta_i-\delta_j)] \tag{3}$$

$$Q_i = Q_{Gi} - Q_{Di}$$

$$= V_i \sum_{j=1}^{N} V_j[G_{ij} \sin(\delta_i-\delta_j) - B_{ij} \cos(\delta_i-\delta_j)] \tag{4}$$

$$\begin{aligned} \delta_{i_{min}} &\leq \delta_i \leq \delta_{i_{max}} \\ V_{i_{min}} &\leq V_i \leq V_{i_{max}} \end{aligned} \tag{5}$$

$(i = 1,2,\ldots,N)$

NOTE.- Some of the δ^s can be negative with respect to slack bus angle δ_1 (chosen to be reference at 0^o).

4. LINEARISED MODEL

Assuming $(\delta_i - \delta_j)$ to be small,

$\sin(\delta_i - \delta_j) \simeq (\delta_i - \delta_j)$ in radians.

$\cos(\delta_i - \delta_j) \simeq 1$

Hence,

$$P_i = V_i \sum_{j=1}^{N} V_j[G_{ij} + B_{ij}(\delta_i - \delta_j)]$$

$$= K_1 + V_i \sum_{j=1}^{N} V_j B_{ij}(\delta_i - \delta_j) \qquad (3A)$$

where, $$K_1 = V_i \sum_{j=1}^{N} V_j G_{ij} \qquad (3B)$$

$$Q_i = -V_i \sum_{j=1}^{N} V_j B_{ij}$$

$$\frac{Q_i}{V_i} = -\sum_{j=1}^{N} V_j B_{ij} \qquad (4A)$$

$$(i = 1,2,\ldots,N)$$

Values of V_i and V_j while calculating K_1 and values of V_i for calculating the ratios of Q_i/V_i in (3B) and (4A) respectively are taken from the 'initial' generation schedule.

The 'modified' equation of f_1 is given by,

$$f_1 = \sum_{i=1}^{N_g} C_{0i} + d_i P_{Gi} \qquad (1A)$$

where,

$$d_i = (C_{1i} + C_{2i} P_{Gi}) \qquad (1B)$$

Values of P_{Gi} are taken from initial generation schedule to calculate the values of d_i in (1B).

Substituting (3A) in (1A), f_1 becomes a linear function of only bus angles. f_2 also likewise becomes a linear function of bus angles.

5. GOAL PROGRAMMING MODEL [7]

Let a_1, a_2 be the aspiration levels, p_1, p_2 be the priorities, d_1^+, d_2^+ be the positive deviations, and d_1^-, d_2^- be the negative deviations, associated with the objective functions f_1 and f_2 respectively. Then the objective function to be 'minimized' in Goal Programming formulation

is $(p_1 d_1^+ + p_2 d_2^+)$
subject to

$$f_1 + d_1^+ - d_1^- = a_1$$

$$f_2 + d_2^+ - d_2^- = a_2$$

and the equations (3A), (4A) and (5).

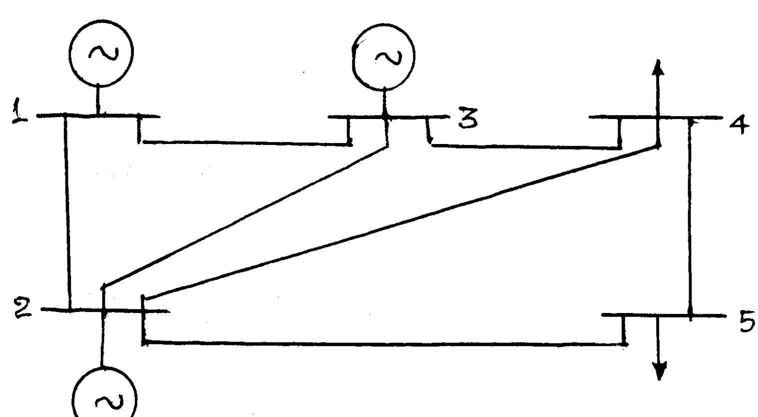
f_1 and f_2 are as given by the equations (1A) and (2) respectively.

[NOTE: p_1, p_2 can either take 1 or 2. a_1 and a_2 are set at zero. ∂_1 is chosen to be zero].

Where,

C_{Oi}, C_{1i} and C_{2i}	are cost coefficients associated with real power generation at bus i
P_{Gi}, Q_{Gi}	active and reactive power generation at bus i
P_{Di}, Q_{Di}	active and reactive power demand at bus i
N_g	number of generator buses $[N_g \subset N]$
N	total number of buses
V_i, V_j	voltage magnitudes at bus i and bus j respectively
∂_i, ∂_j	bus angles at i and j nodes respecively
G_{ij}, B_{ij}	conductance, susceptance between bus i and bus j
$\partial_{i_{max}}, \partial_{i_{min}}$	maximum and minimum limits of bus angle ∂_i
$V_{i_{max}}, V_{i_{min}}$	maximum and minimum limits of bus voltage magnitudes at bus i.

6. DATA [8]



5-Bus, 7-line, 3-generator system.

Table 1: Cost coefficient data [9]
(P_{Gi} are expressed in p.u.)

C_{2i}	C_{1i}	C_{0i}
60	200	140
75	150	120
70	180	80

Table 2: Line data.

Bus code p-q	Impedance z_{pq}	Line charging susceptance $y'_{pq}/2$
1-2	0.02 + j 0.06	0.0 + j 0.030
1-3	0.08 + j 0.24	0.0 + j 0.025
2-3	0.06 + j 0.18	0.0 + j 0.020
2-4	0.06 + j 0.18	0.0 + j 0.020
2-5	0.04 + j 0.12	0.0 + j 0.015
3-4	0.01 + j 0.03	0.0 + j 0.010
4-5	0.08 + j 0.24	0.0 + j 0.025

Table 3: Bus data

Bus code	Assumed bus voltage	Generation		Load	
		MW	MVAR	MW	MVAR
1	1.06 + j 0.0	0	0	0	0
2	1.00 + j 0.0	40	30	20	10
3	1.00 + j 0.0	0	0	45	15
4	1.00 + j 0.0	0	0	40	5
5	1.00 + j 0.0	0	0	60	10

Table 4: Initial generation schedule (from load flow)

Bus	Voltage Magnitude (pu)	Angle	Generation (pu) P_G	Q_G	Load (pu) P_D	Q_D
1	1.06	0.0	0.984	-0.232	0.0	0.0
2	1.056	-2.27	0.4	0.3	0.2	0.1
3	1.044	-3.67	0.3	0.1	0.45	0.15
4	1.041	-4.16	0.0	0.0	0.40	0.05
5	1.031	-5.31	0.0	0.0	0.60	0.10

7. RESULTS

Giving higher priority to f_1 compared to f_2, the optimal solution is obtained as:

V_1 = 1.0415 p.u. $\quad\delta_1$ = 0.00000 radian

V_2 = 1.0500 p.u. $\quad\delta_2$ = -0.01700 radian

V_3 = 1.0487 p.u. $\quad\delta_3$ = -0.03125 radian

V_4 = 1.0489 p.u. $\quad\delta_4$ = -0.043536 radian

V_5 = 1.0447 p.u. $\quad\delta_5$ = -0.068659 radian

P_{G1} = 0.4575 p.u.; P_{G2} = 0.64212 p.u.; P_{G3} = 0.63189 p.u.

Total generation = 1.7315 p.u.

f_1 = cost of real power generation = 697.35 dollars/hr.

f_2 = 0.0815 p.u. (total transmission losses).

8. CONCLUSIONS

Goal programming approach is shown to be a useful tool for solving multiple objective optimization problems in power systems. In the above problem both objective functions and constraint equations are linearised so that linear goal programming can be applied. With certain amount of refinement of the model, viz., bringing in line flow constraints etc., it is hoped that the model can be used for real time applications in power systems.

9. REFERENCES

[1] Albert M. Sasson, ''Non-linear programming solutions for load flow, minimum-loss and economic dispatching problems'', IEEE Trans. on Power Apparatus and Systems, Vol. PAS-88, No.4, April 1969, pp.399-407.

[2] Albert M. Sasson and Hyde M. Merrill, ''Some applications of optimization techniques to power system problems'', Proceedings IEEE, Vol.62, No.7, July 1974, pp.959-972.

[3] N. Naboka and L. Freris, ''Optimization of economic dispatch through quadratic and linear programming'', Proceedings IEEE, Vol.120, May 1973, pp.574-579.

[4] J.L. Bala and A. Thanikachalam, ''An improved second order method for optimal load flow'', IEEE Trans. on PAS, Vol. PAS-97, No.4, July/Aug. 1978, pp.1239-1244.

[5] I. Megahed, N. Abou-Taleb and M. Iskandrani, ''A modified method for solving the economic dispatching problem'', IEEE Trans. PAS, Vol. PAS-96, No.1, Jan./Feb. 1977, pp.124-133.

[6] R. Romano, V.M. Quintann, R. Lopez and V. Valdez, ''Constrained economic Wolfe decomposition principle'', IEEE Trans. on PAS, Vol. PAS-100, No.4, April 1981, pp.2127-2137.

[7] Lee Sang, M., Goal Programming for Decision Analysis, Auerback Publications Inc., Philadelphia. 1972

[8] G.W. Stagg and A.H. El-Abiad, Computer Methods in Power System Analysis, McGraw-Hill, New York, 1968.

[9] R.B. Gungor et al., ''A technique for optimising real and reactive power schedules'', IEEE Trans. on PAS, Vol. PAS-90, 1971, pp.1701-1709.

THERMAL ENERGY - STORAGE

V.K. Nema, S.K. Agrawal*

Department of Mech. Engineering,

Motilal Nehru Regional Engineering College,
Allahabad - 211 004 (INDIA)

ABSTRACT

With the gradual depletion of oil reserves and conventional fuels, it is warranted to appreciate the role of renewable energy sources, and that of the efficient energy-storage systems. Sources of energy, needing storage, are either the waste heat from industries or surplus energy during the low energy demand periods. Among the various methods of energy storage, worth mentinoning are mechanical energy-storage in flywheels, compressed air energy-storage (CAES), underground pumped hydroprojects (UPH), magnetic energy-storage, sensible and latent thermal energy-storage and techniques using hybrid systems. The paper reviews various developments in the field of thermal energy-storage.

1. INTRODUCTION

Energy storage involves the collection and retention of the readily available energy in a form such that it may be recovered later. Often sources of energy needing storage are either the waste heat from industries, surplus energy during times of low energy demand or the solar energy during day-light hours with clear sky. The underground pumped hydro-electric storage system (UPH) pumps water from a rock-encased lower reservoir, hundreds of feet below the ground surface to the upper reservoir using surplus electricity. The compressed air energy storage (CAES), a low-cost system to store offpeak power, is useful in conjunction with gas turbine plants since two-third of energy produced is needed to operate the compressor stage. With the

* Presently Lecturer in the Department of Mechanical Engineering, University of Al-Fateh, Tripoli, LIBYA.

development of cellulosic rotors, flywheels have now become cost competetive and attractive because of their high durability, power capacities and efficiency [1]. The lead acid batteries are too expensive for electric utilities [2]. The Super-conducting magnets represent the only storage system in which electric energy is stored directly. It is in the experimental stage and the capital cost for utility application appears to be too high to be attractive [3].

Energy can be stored thermally by heating (Sensible heat storage), melting or evaporation (Latent heat storage) of materials. Thermal energy-storage (TES) does not appear to be cost competetive with UPH or CAES for power generating stations. However, considerable application of TES heaters fo residential space has taken place in Germany and other countries [3]. The present paper reviews the progress in the field of TES.

2. VARIOUS MEHODS OF TES

2.1 Sensible Heat Storage (SHS)

Among the various methods of TES, SHS is attractive from economic considerations. Water is an excellent medium for SHS below 100° C. The above ground can be used for storing hot water. High-temperature heat storage requires pressurization of water. Cost of equipment increases by a factor of 2.75 when the storage temperature changes from 210° to 300° C. The capital cost due to high pressure containment may be reduced by underground storage in caverns. By pressurizing the caverns, thin-walled vessels may be used. The most commonly proposed substitutes for water are petroleum-based heat-transfer oils or molten salts. The former are costly and are associated with the problems related to flammability and availability, and are generally limited to 350° C [4].

Solids constitute an attractive high-temperature heat-storage medium because of their high heat capacity and low vapour-pressure, low pressure-drop through the bed, and high heat transfer coefficient from solid to air. they permit direct contact heat exchange and very low material cost. They are widely used in Europe mostly for space heating. The bricks are stacked to form chambers and operating temperatures are around 750° C, the bulk temperature droping continuously during discharge [5,6].

Koizumi et al. [7] reported that Japan had introduced a solar air-heating collector, using underground rock-bed heat-storage system, for residential buildings. Scrap iron and magnetite exhibit, over a wide temperature range, nearly the same volumetric heat capacity as water. Concrete, while not as efficient volumetrically as water and scrap iron or magnetite, has obvious advantages for residential heating [3]. A packed bed storage uses the heat capacity of a bed of loosely packed particulate material to store energy. A variety of solids may be used. Crushed stone (rock) roofs have been in use for many years. A fluid usually air is flown through the bed upwards while adding and downwards while removing energy [2,8].

References [9,10] utilise the heat capacity of the earth. The system consists of excavating a cavity, installing a grid of pipes for heat transfer and then back-filling the excavation. Storage capacity and input rates are high and the cost is low.

Ridgway et al. [11] showed that the steel-lined cavities deep underground using the rock to provide containment were economical and practical in large capacities for TES. By reducing the cavity pressure, steam is flushed from the hot water and used to drive peaking turbines when needed. The effective storage density about 18 kWh/m^3 is 20-50 times that of usual pumped hydro-system. A subsurface (earth and rock) storage is insulated against variation in temperature and holds energy for long time with minimum heat loss [12]. Hardy [13] identified six constuction schemes for large scale TES in rocks. Lindblom [14] used subsurface for TES to conserve some of the themal energy in rock caverns, bore-hole storage in rocks, in clay and in aquifers. Sodium nitrate (melting point 308° C), retained within porous ceramic matrices such as refractory bricks, may be used as a model material for TES [15]. There is no chemical reaction and weight loss up to 500° C.

Solids, such as sand and alumina, can be used at temperatures of the order of 1000° C by fluidization. Shallow fluidized bed heat exchangers with immersed finned tube heat-transfer surfaces offer high operational efficiency. Fouling and damage to the distributor can take place in the above techniques when used to recover heat from very dirty and corrosive gases at high temperatures. Solution to this problem is the usage of the falling cloud heat exchanger [16-18]. Bergougnou et al. [17] found analytically for cylindrical storages (having diameter equal to length) that mostly 100% heat could be retained up to 60 hours in 25 m cylinder; 85% could be retained upto 35 hours in a 4 m cylinder. It is advantageous to use smaller particles (less than 0.4 mm) to reduce radial heat losses while storing and sensible heat losses during transportation.

Turner and Awaya [19] found that, for a stationary sand bed, very closely-spaced heat transfer tubes throughout the volume are required, while the moving sand past or around pipes is intended to reduce the power-related cost at the penalty of added system-complexity. Low temperature gas stream in fluidized bed of ballotini particles was reported by Harkar and Hindmarch [20].

Heat rejected during cooling in the summer can be stored and used for heating in the winter. Solar energy can be collected the year-round and used during limited periods. Man-made storages of the required capacity are uneconomical for most systems. The paper [21] represents a TES provided naturally by aquifers and has a sufficiently large capacity on an annual basis. Aquifer TES has been reported very promising at places where seasonal variance in climate is significant and aquifers exist abundantly [22-24]. Meyer [25] has examined the possibility of using underground water bearing transformations (aquifers) to store water for later use.

2.2 Latent Heat Storage (LHS)

The latent heat of phase change is an attractive approach for TES. It offers the advantage of high temperature operation and the high storage capacity, but may suffer from high cost of material. Suitable phase change materials (PCM) are selected to melt at the desired temperature with a high heat of fusion. The heat of fusion of various PCM in the temperature range 38° C to 538° C are listed in reference [3]. Most organic materials have weak crystal lattices and hence low heats of fusion. Inorganic salts generally melt at undesirably high temperatures. Inorganic hydrates, in place of melting, decompose at desirable temperatures [3].

To maintain a termperature of about 30° C in house heating applications, Glauber Salt (Sodium sulphate decahydrate) appears promising, and was the earliest PCM studied experimentally. [26]. Recently a LHS unit has been devised using Glauber Salt. Heat is transferred in a closed container to the LHS material by means of the vapour of a heat transfer liquid. Surface active additives produce optimum conditions for the heat transfer.Heat storages can be performed with high energy densities in narrow temperature differences [27]. The 3:2 mixture of hydrated salts of Na $C_2H_3O_2 \cdot 3H_2O$ and $Na_2S_2O_3 \cdot 5H_2O$ has been reported to offer a maximum storage capacity of 224 kJ/kg at 39° C. These salt-mixtures have been found to form supercooled melts which crystallize even at temperature below - 10° C [28]. For domestic water heating (about 60° C), hydronic space heating (70°-90° C) etc., urea and inorganic salt eutectics look particularly promising [26]. Kauffman [29] used saturated aqueous salt solutions which dissolve endothermically for TES at temperatures 0-120° C suitable for solar space-heating, water-heating and air-conditioning. Latent heat of crystallization is continuously released on cooling and absorbed on heating.

Bundy [30] proposed a storage system for use with a nuclear racator. Heat transfer from eutectic mixture of NaF/FeF_2 as PCM to the heat transfer fluid (molten lead) is of direct contact type and takes place in a large cylindrical tank containing molten salt. A conventional heat exchanger is then used to transfer heat from molten lead to the turbine working fluid.

Ferric chloride and Lithium nirate are useful for high temperature LHS (360° C) [3]. Birchenall and Telkes [31] found halides and oxides as PCM in 200-800° C range. Turner and Truscells [32] applied sodium hydroxide as PCM for a large scale TES at 450° C. They used a cylindrical shell (3.6 m dia x 18 m length) with closely spaced internal tubes; salt filling the space between the tubes and the outer shell. To charge the system, superheated steam flowing through the tubes melts and raises the temperature of NaOH; for discharge, pressurized water flows through the same tube bundle. Sodium sulphate was reported suitable for low quality heat storage by Hallett and Keyser [33]. Marianowski and Maru [34] concluded that the alkali carbonate mixtures are attractive in the range

455-555° C because of high thermal conductivity, low volumetric expansion on melting, low corrosivity, good stability and acceptable storage capacites. Eichelberger and Gillman [35] found that metal fluorides are adequately available for widespread TES and are cost effective between 400°-1000° C. Salyer et al. [36] reported that high density polyethylene was a low cost material with high heat of fusion, thereby is an efficient TES for heating and cooling buildings. Galloway [37] explored the use of paraffin wax as PCM for domestic solar energy heating system. The system was found economically competetive with electric resistance heating and were more attractive than systems without PCM. Taube and Furrer [38] utlised ammoniated salts and undertook construction of 5 to 10 kW pilot units. Marianowski [39] studied the storage of high quality heat in temperature range 850-1000° C for high inputs from solar concentrators and off-peak energy from power plants. He found that carbonate- and chloride-mixtures are best suited for this purpose.

3. CONCLUSION

In the past the energy storage was limited to storage of fuels, namely, natural gas and pertoleum; but with the passage of time, the field of surplus energy storage gained momentum. At least one hundred large scale heat storage projects can now be found throughout the world. Introductory information on technologies, systems, locations, principal investigators is available in the reference [40]. It is clear from the that foregoing review that TES methods are best suited for specific applications. Largely it may be said that sub-surface energy-storage methods when integrated with nuclear plants are most cost effective.

REFERENCES

[1] - David, L.H.; Arthur, G.E.; Darrel, A.F., "Design of Flywheel rotors utilising Cellulosic materials", 14th Intersociety Energy conference, Boston, Massachusetts, p 368-373, Aug. 5-10, 1979.

[2] - An Assessment of Energy Storage Systems suitable for use by Electric Utilities, Report EPRI EM-264, Electric power Research Institute, Palo, Alto, California, July, 1976.

[3] - Penner, S.S.; Icerman, L., Energy Volume II, Addison-Westley Publishing Company, inc., Massachusetts, 1975.

[4] - Green, R.M.; Ottensen, D.K.; Bartel, J.J.; Bramlette, T.T., "High temperature Thermal Energy storage", Sharing the Sun! Solar Technology in the Seventies, Joint Conf. American Sec., International Solar Energy society and Solar Energy society of Canada Inc., V 8, p 4-47, Aug. 15-20, 1976.

[5] - Anon, "Off-Peak Electric Thermal Storage for Industrial Process Heating", The Engineer, V 226, p

549, Oct. 1968.

[6] - Field, A.A., "Storage heating by Low Cost Electricity" Heating, Piping and Air conditioning, V 43, n 2, p 75, Feb. 1971.

[7] - Koizumi, Y.K.; Murasaki, H.; Itoh, T. and Matsui, K., "Experimental and Analytical study of Rock-bed storage", Energy development in Japan, V 1, n 2, p 153-166, 1978.

[8] - Duffie, J.A.; Beckman, W.A., Solar Engineering of Thermal Processes, p 326-349, John Wiley, New York, 1980.

[9] - Garg, S.C., "An earth Heat-sink Concept for Underground power Sources", TN H-1261, Naval Civil Engineering Laboratory, Part Hueneme, California, Feb. 1973.

[10] - Garg, S.C., "Earth Heat Sinks for Underground Power Sources", TN. N-1306, Naval Civil Engineering Laboratory, Port Hueneme, California, Aug. 1973.

[11] - Ridgway, S.L.; Dooley, J.L.; Hammond, R.P., "Large Energy Storage system for utilities", App. Energy, V 6, n 2, P 133-142, Mar.-April 1980.

[12] - Bordia, O., Bjustrom, S., "Subsurface Energy Production, Storage and distribution", Underground Space, V7, n 4-5, Feb-Apr 83.

[13] - Hardy, M.P., Albertson, V.D., Bligh, T.P., Riaz, M., Blackshear, P.L., "Large Scale Thermal Storage in rocks: construction, utilisation and economics", proceedings Intersec. Energy Conference, 12th, Washington, D.C.. V 1, p 583-590, Aug. 28-Sept. 2, 1977.

[14] - Lindblom, U.E., "Underground Thermal Storage techniques for Developing countries", Underground Space, V 7, n 45, Feb-Apr 1983.

[15] - Utsunomiya, Taizo; Hoshino, Hoji; Hoshino Yosihio, "Studies on Sodium Nitrate/ceramic Composite Thermal Energy Storage", Rep Res Lab Eng Mater Tokyo Inst Technol, n 11, p 27-35, 1986.

[16] - Botterill, J.S.M.; Salway, A.G.; Teoman, Y., "Heat losses from a High temperature particulate bed Storage", Int, Conf. on Energy Storage, Brighton, UK, p 101-112, Apr 29-May 1, 1981.

[17] - Bergougnou. M., A.; Botterill, J.S.M.; Howard, J.R.; Newey, D.C.; Salway, A.G., Teoman, Y., "High temperature heat Storage, Future energy concepts", SEE, Conference publication, n 193, p 61-64, 1981.

[18] - Botterill, J.S.M.; Salewy, A.G.; Teoman, Y.; "High Temperature Heat Storage", I. chem. E., Symposium series no. 78.

[19] - Turner, R.H.; Awaya, H.I.; "High Temperature Energy Storage in Moving Sand", Proc. Intersoc. Energy

convers, Eng. Conf. 13th. San Diego, Calif., p 923-927, Aug. 20-25, 1978.

[20] - Harkar, J.H.; Hindmarch, C.E.; "Energy Storage in Fluidized beds" J. Inst. Energy, V 52, n 410, p 45-48, 1979.

[21] - Schaetzle, W.,J.; Brett, C.E.; Grubbs, D.,M., "Annual Thermal Energy Storage in ground water aquifers", Proc. of Sol. Energy Storage Options, V 1, San Antonio, p 183-192, Mar. 19-20, 1979.

[22] - Anon, "Seasonal Thermal energy Storage", Mech. Eng. V 105, n 3, p 28-34, Mar 1983.

[23] - Moltz F.J.; Melville, J.G.O.; Parr, A.D., "ATES: An attempt to counter free thermal convection", Water Resource Res V 19, n 4, p 922-930, Aug. 1983.

[24] - Yokoyama, Takao; Uemiya, H; Katayama, K.; Katsuraji, K, "Realization of Recoverable zone from the stand point of flow lines", Bull JSME, V 26, n 217, p 1162-69, Jul. 1983.

[25] - Meyer, C.F., "Large scale Thermal energy storage for Cogeneration and Solar systems", Constr., specifier, V 31, n 6, p 46-50, 52-55, Jun. 1978.

[26] - Swet, C.J., "New Directions in Heat storage for Buildings", Sharing the Sun! Solar Technology in the seventies, Joint Conf. American Sec, International Solar Energy Society and Solar Energy society of Canada, Inc, V 8, p 1-3 aug. 15-20, 1976.

[27] - Emons, H.H., Naumann, R.; Voigt, W, "Application cf Glauber Salt in a new type of a Latent heat Storage unit", Inst. J. Energy Res, V 10, n 1, p 69-74, Jan.-Mar 1986.

[28] - Barrett, P.F.; Best, B.R., "Thermal Energy Storage in Supercooled Salt misture", Mater Chem Phys, V 12, n 6, p 529-536, Jun. 1985.

[29] - Kauffman, K.W.; Lorsch, H.G., "Thermal Energy Storage with Saturated aqueous Solutions", Sharing the Sun! Solar Technology seventies, Joint conf. Am., Sec. Int sol. energy Soc., & Sol. energy Soc. of Canada V 8, p 227-237 Aug. 15-20, 1976.

[30] - Bundy, F., "Power Generating Plant with Nuclear reactor/Heat Storage Combination", US Patent no. 3, 848, 416, Nov. 1974.

[31] - Birchenall, C.E.; Telkes, M, " Thermal Storage in Metals", Sharing the Sun! Solar Technology in the seventies; Joint conf., American Section, Int. Solar Energy Society & Solar Energy Soc., Canada, V 8, p 138-154, Aug. 15-20, 1976.

[32] - Turner, R.H, Truscell, V.C., "Large scale thermal energy using sodium hydroxide", Proc. of the Annual Meeting Am. Sect. of the Int. Sol. Energy Soc., V 1, Orlando, Fla, Sect 18, Sess E 4., Jun 6-19, 1977.

[33] - Hallett, J; and Keyser, G., "Power Characteristics of a continuous crystallization Latent heat recovery system", ASME pap 79, Sol-2 for Meeting Mar. 12-15, 1979.

[34] - Marianowski, L.G.; Maru, H.C., "Latent heat Thermal energy storage systems above 450° C", Proc. Intersoc., Engergy convers. Eng. conf. 12th, Washington DC, p 555-566, Aug. 28-Sep. 2, 1977.

[35] - Eichelberger, J.L.; Gillman, H.D., "Investigation of metal fluroide Thermal Energy-storage materials", Proc. Intersoc. Energy convers Eng. conference 12th, Washington, DC, p 567-574, Aug. 28-Sept. 2, 1977.

[36] - Salyer, I.O., Bothvam, R.A., Jenkins, G. H., Bell, G.L., "Form Stable crystalline polymer pellets for TES, Proc. Intersoc, Energy convers Eng. Conf., 13th, San Diego California, p 948-962, Aug. 20-25, 1978.

[37] - Galloway, T.R., " Paraffin Wax Heat-storage for Solar heated homes", Proc. Intersoc. Energy convers. Eng. conf., 13th, San Diego, Calif. p 963-969, Aug. 20-25, 1978.

[38] - Taube M.; Furrer M., "Opportunities and limitations for the use of Ammoniated Salts as a carrier for thermo-chemical energy storage", Doc. Swed. Counc Build. Res D 25, 1980, proc. Int semin on Thermochem Energy Storage R Inst. of Technol, Stockholm, Swed, p 349-370, Jan 7-9, 1980.

[39] - Marianowski, L.G.; Maru H.C.; Camar, E.C., "Latent heat Thermal Energy Storage at high temperature", Proc. of the Southest Conf. on Appl. of solar Energy, no 2 Baton, Rough La, Apr. 19-22, 1976.

[40] - Lundin, Sven-Erik [Ed.], Large scale Thermal energy Storage projects-in Operation or under Construction Sweedish Council for Building research, Sweden, 1985.

OIL CONSERVATION USING FLYWHEEL ENERGY

S.C. Tripathy R. Balasubramanian G.V.S.K. Rao

Centre of Energy Studies

Indian Institute of Technology

New Delhi - 110 016

INDIA

ABSTRACT

This paper presents digital computer simulation of the flywheel energy storage system to assess its economic advantage. Actual data pertaining to a particular Delhi bus route have been collected and used in the simulation study. In the flywheel energy storage system, an electromagnetic braking torque is applied to the rear wheels of the vehicle to decelerate it before a stop. The kinetic energy of the vehicle is used to do work against the electromagnetic braking torque (opposing torque) which is converted into electrical energy by using a generator. This electrical energy, in turn, is converted into mechanical energy and is stored in the flywheel, which is retrieved by a reverse operating process, to accelerate the vehicle after a stop.

1. INTRODUCTION

It is well known that the internal combustion engine (ICE) using gasoline is used to propel city buses. To conserve the scarce and valuable gasoline, it is proposed that an energy storage system consisting of a flywheel and electrical subsystem be used instead of wasting energy in friction brakes in stopping the bus. This stored energy can be used in accelerating the bus after a stop. When the flysheel is discharged to a low speed, the ICE takes over the control and provides the required power for further acceleration. In this way the amount of fuel consumed is saved.

In the next stopping operation, the flywheel will be charged again and will produce energy for next acceleration. Even though, the fuel saved though this type of complicated operation is small for a single start-stop

cycle, when this value is integrated over number of stops in a day, it will be of considerable amount. In a complete fleet of vehicles, the fuel expenditure will be heavily reduced.

The electric transmission system for the hybrid propulsion [1] requires two machines and associated power controlling equipment. These machines must be capable of (1) generating energy by converting from mechanical energy to electrical energy and (2) motorizing by recovering electrical energy to mechanical energy. Separately excited DC machines are capable of these modes of conversion when armatures of two of these motor-generators are connected electrically together. The entire control process can be accomplished by the coordinated, separately excited field control of the two machines.

The advantage of using DC machines is its light weight, simple power control equipment, but on the disadvantages side, the mechanical commutator imposes restrictions on rotational speeds, the electrical loading and the operating environment of the DC electrical loading and the operating environment of the DC electrical machine. This is because of structural, thermal wear and sparking considerations of the mechanical commutator. The DC machine neither can be operated at flywheel speeds nor can be operated within the low pressure flywheel chamber. A speed reducer between a flywheel and commutator machine requirement is also a problem. The machine is also heavy. By using solid state devices as a supplement of this mechanical commutator, a smaller directly driven hermetically sealed flywheel machine can be considered. The flywheel cavity may contain helium or hydrogen for cooling at 1 psia.

2. THE SYSTEM SIMULATION

The complete behaviour of the flywheel energy storage system mainly depends on the flywheel speed and inertia. The rate of charging and discharging of the flywheel depends upon the deceleration and acceleration of the vehicle. The machines associated with the system are considered as DC machines. In a DC machine the load torque depends on load current and field current; field current in turn controls the back emf of the motor and the output voltage of the generator in accordance with the speed. In actual operation the speed of the flywheel decreases while the vehicle is decelerating. The field currents must be so adjusted that they should take into account these speed relations and at the same time should control the energy transfer.

The system's economic feasibility depends on the fuel savings that this system can provide. The main aim of this project is evaluation of the fuel savings. This can be accomplished by comparing the fuel consumption of two vehicles, one with a flywheel energy storage system and

the other without any flywheel energy Storage System.

The main data input to the simulation programme is the driving cycle. It is a time versus velocity plot of a bus. To get the driving cycle, a survey has been conducted for a complete day on a Delhi Transport Corporation (DTC) bus running on route from Munirka to Plaza. The DTC officials helped by providing an extra speedometer in the bus and it is so placed that it is visible from the first passenger seat, just behind the driver. With the help of this speedometer, a digital watch and a cassette recorder, the readings of the speedometer have been recorded at every five seconds interval. This type of recording has been carried out throughout a complete day for a total of six trips. Later graphs have been plotted with these readings. From these plots, one driving cycle has been selected for the simulation. To determine the transmission gear ratio, the engine tone has been recorded. From the engine tone, the shift points have been determined. The DTC officials also helped in obtaining the vehicle's physical and mechanical data.

Two DC machines are assumed for the simulation. Their output voltage, power, speed and field current are all assumed. All these assumptions are within practical limits. A computer programme has been developed in Fortran IV on a digital computer, ICL 2960. Two flywheels have been considered with the same energy but with different speeds and inertias. It has been tried to evaluate the parametric behaviour of the system with these two different flywheels for the same driving cycle.

3. THE DRIVES OF THE SYSTEM

The flywheel as well as the traction machine may be either a DC motor or a DC driven AC motor. In the latter it has been called as "Commutatorless DC motor'. It possesses all the flexible characteristics of a DC motor and without any mechanical commutator problem. But this type of machine is not a self-starting machine unless shaft position sensor signals can be derived even in motor stand still condition.

Two schemes have been already developed for the starting of the machine. In one scheme, a shaft position sensor has been used in an indirect way and the commutation of the main inverter thyristors has been achieved by using a capcitor and two auxilliary thyristors, used in lower speeds of the motor. This scheme enables the motor to work as a commutatorless DC motor. In the second scheme, during the starting and low speed periods, the commutation is achieved by interupting the DC link current six times per cycle. A low frequency AC has been derived from the inverter and is used in starting the machine. Once the machine reaches considerable speed, rotor sensor signals are derived from sensing the motor terminal voltages.

In the new scheme developed in this paper both the above two schemes have been combined. A low frequency AC has been derived from the inverter, but the DC voltage source is a three phase uncontrolled rectifier. So there is no possibility of interupting the DC link current without using extra converter (DC - DC). So in this new scheme commutation is achieved by using a capacitor and two auxiliary thyristors, as in the case of first scheme. The ratings of the capacitor and the two auxiliary thyristors can be a fraction of the full machine ratings as they are in need of use during starting only. The frequency of the inverter output is controlled by a function gererator, from which the reference pulses have been derived. For successful commutation in all modes of operations, a capacitor voltage sensor circuit has been employed.

The motor has been starting with an input of 1 Hz AC with a reduced dc voltage. Once the motor (synchronous) synchronizes with this frequency, both frequency and the DC voltage have been increased slowly till the motor reaches 300 rpm. The speed of 300 rpm is sufficient to load commutate the inverter main thyristors and the motor terminal voltage can be used for generating synchronizing pulses for the inverter. The latter case is out of scope in this paper.

4. SYSTEM TYPES

This work documents the investigation of a Heat Engine/ Flywheel Hybrid propulsion configuration that employs an electrical transmission in addition to the existing Heat Engine to transfer energy between an energy storage device and the vehicle. The electrical transmission system is shown in Fig. 1.

There are three types of transmission system options

	Flywheel input/ output Machine	Traction Machine
1.	DC	DC
2.	AC	DC
3.	AC	AC

In this project work only DC - DC system is under investigation.

The primary use of any transmission system is to augment the heat engine with energy from the flywheel in such a way as to level engine loads and improve the overall vehicle efficiency. The benefits of using this hybrid system are as follows:

1. Provides fuel economy which is not possible with any other conventional propulsion arrangements.

2. There will be reduction in contribution to the pollution as the fuel consumption is reduced.

5. THE TECHNICAL APPROACH

Fig. 2 is the basic structure of the total system of the Heat Engine (HE)/Flywheel (FW) hybrid propulsion configuration and the HE and FW simultaneously supply the power to the rear wheels of the vehicle. Power can be supplied both from the HE and the FW simultaneously or either only from HE or FW. When HE is alone supplying power the electrical transmission system can be cut off.

To explain the operational behavior of the system we start with assumption that the FW is at rest. The traction Machine (TM) Motor/Generator (M/G) system acts as a generator. It converts the mechanical energy from the HE to electrical energy and this electrical energy is fed to the FW M/G system. The FW M/G system now acting as a motor converts the input electrical power into mechanical power.

This developed mechanical power is used to rotate the FW and is stored in the FW as it gains speed. This mode of FW charging operation continues till the FW attains about 150% of the rated speed.

The next mode of operation is the acceleration of the vehicle (bus). In this mode of operation the FW M/G system acts as a generator and the TM M/G system acts as a motor. The FW acting as the prime mover of the FW M/G system generates electrical power and this power is fed to the TM. It converts this power into mechanical power and this mechanical power accelerates the vehicle.

The accelerating mode in which the total required power is supplied completely by the FW continues till the FW discharges to approximately 50% of the initial speed. Then the HE will be turned on and the required power will be split between the HE and FW. The ratio of this power split will be such that HE operates in its low speed region. Once the FW discharges to 25% of the initial speed the HE supplies the total required power alone. By this time the bus reaches considerable velocity state.

In the third mode of operation the kinetic energy of the moving vehicle is to be transferred to the FW. The TM M/G system acting as a generator and the jack shaft of the vehicle acting as the prime mover convert the kinetic energy of the vehicle into electrical energy. This electrical energy is fed to the FW M/G system now acting as a motor. This converts the electrical energy input into mechanical energy. The mechanical energy accelerates the flywheel and hence it will be charged. This stored energy is reused in the next acceleration mode of the vehicle.

6. SYSTEM INTERACTION

Fig. 3. shows how the system interacts with the HE and the driver. When the driver depresses the accelerator pedal, he provides power to the rear wheels that is proportional to the pedal displacement. The Driver Control Unit (DCU) stores the driver's control law, energy management schedules, power split and engine ON - OFF schedules. It has to be assumed that the engine will be turned on during power split and constant or final velocity operating conditions. For the rest of the time the HE is kept off i.e. during the period when the vehicle is being driven completely by the power from the flywheel and during retardation periods.

The driver control law depends upon the accelerator pedal displacement during acceleration and upon the brake pedal displacement during regenerative braking.

The power split conditions are stored in such a way that the DCU gives command to the heat engine to develop the power that depends upon the total power requirement and the power split and the vehicle state.

The status of the vehicle ($\frac{\Delta V}{\Delta T}>0$, $\frac{\Delta V}{\Delta T}>>0$, $\frac{\Delta V}{\Delta T}=0$, $\frac{\Delta V}{\Delta T}<0$) is determined by the DCU which sends the signals to Electric control Unit ECU to servo clutches (If an actual hybrid system has to be incorporatted, the design of the clutches has to control some extra parameters in addition to the existing components), to series servo of the HE and to the energy storage unit. The series servo modulates the carburator independent of the driver's input and without disturbing his desired command.

The DCU receives the six identified inputs to control the vehicle. The ECU in addition to controlling electrical power elements, monitors and controls the machinery to prevent hazardous operation.

7. THE DC - DC OPERATION

The function of the Power Control Unit (PCU) is to provide the power interface between the traction and flywheel machines. The power controlling Unit controls the direction of power flow as well as the power being exchanged between the two machines. The control logic provides the necessary intelligence to the system. It accepts signals from the vehicle control system, and converts into commands for power controlling unit. The control logic also controls.

8. THE DRIVING CYCLE INPUT

The observed driving cycle of a DTC bus is used as the basic driving cycle criteria in determining the optimum fuel consumption for study. The driving cycle is shown in Fig. 4. The cycle is specified in terms of discrete

bus velocity increments given at 5 sec interval. To input this velocity profile as a command to the bus, a relationship between commanded velocity and bus velocity needs to be determined.

The vehicle considered for study is an Ashok Leyland's Viking model, a DTC bus, operated in route 615 between Munirka and Plaza.

9. THE FUEL SAVINGS

The fuel savings are mainly dependent upon the initial flywheel speed. In the first driving cycle, the flywheel is charged from the heat engine. It can be charged to considerably high speeds. But in later stage it has to be charged by the regenerative braking. So in the second start-stop cycle, the initial flywheel speed will be different from the initial speed of the first start-stop cycle. The fuel savings also depend upon the power split. If the power split is low, the power to be delivered by the traction motor would be low and the flywheel can give power to some more extent. But the power developed by the heat engine will be more and hence fuel consumption will be more. If the power split is high, the engine power during the power split may be low, but as the power developed by the flywheel is high, its rate of discharge will be high. Some compromise has to be assumed regarding the power split. Variation of the power of TM & FW I/O devices for 9000 rpm flywheel is shown in Fig. 5.

In this simulation the fuel savings obtained theoretically have been found to be on an average 35.5%.

10. CONCLUSIONS

Flywheel energy storage system is very much useful for conservation of energy. In this work study has been done regarding the system where it has been considered for a city bus. But the system is also useful for battery cars, suburban electric trains and also any heavy machines or in general to any system which is subjected to frequent starts and stops.

The main attraction of the system is the flywheel. By designing it properly, fuel savings upto 50% can easily be achieved. In the work so far discussed here there are so many assumptions and approximations which are the main reasons for achieving only 35.5% fuel savings. Practically electric machines with high efficiency may not have an efficiency figure as low as 85%. It may be more than that.

The commutatorless DC motor is one of the best options for an electric drive. In this work the emphasis has been given to the motor starting problem only and that too in relation with the flywheel energy storage systems. But it is useful for other purpose also. In battery cars,

even without employing this system, the same drive can be used as the main transducer from electrical power to mechanical power. It can be operated at high speeds as it does not have any constraints imposed by the mechanical commutator.

It has been proved that the motor need not be started as a commutatorless DC motor, it can be started as an inverter driven synchronous motor and then can be modified into the commutatorless DC motor mode.

11. REFERENCES

[1] - 'Study of Heat Engine/Flywheel, Hybrid Propulsion Configuration with Electrical Transmission System" U.S. Department of Commerce, National Technical Information Service, ALO - 41/1, April, 1978.

[2] - Robert L. Steigerwald and Thomas A Lipo, "Analysis of a Novel Forced Commutated Synchronous Motor Drive' IEEE Transactions on Industry Applications, Vol. IA 15, No. 1, January/February, 1979.

[3] - R. Venkataraman and B. Ramaswami: "Thyristor Converter Fed Synchronous Motor Drive", Electric Machine and Electro Mechanics, Sept/Oct. 1981. 6, 433 - 449.

[4] - J.M.D. Murphy, Thyristor Control of AC Motor, Pergamon Press.

[5] - A.B. Plunkett and F.G. Turnbull "Load Commutated Inverter Synchronous Motor Drive without a Shaft Position Sensor" IEEE Trans. on Industry Application 1979, 63 - 71.

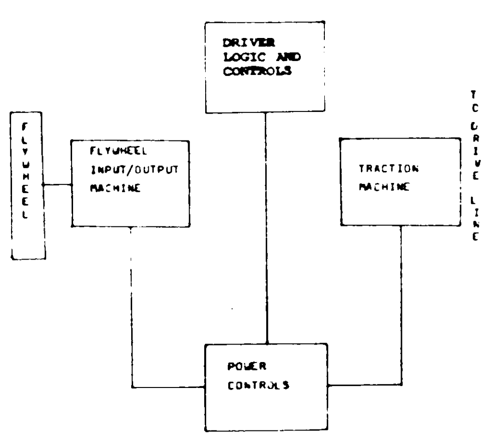


FIG. 1. ELECTRICAL TRANSMISSION SYSTEM

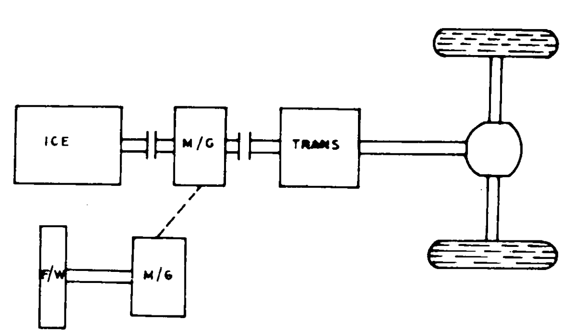


FIG. 2 SYSTEM BLOCK DIAGRAM

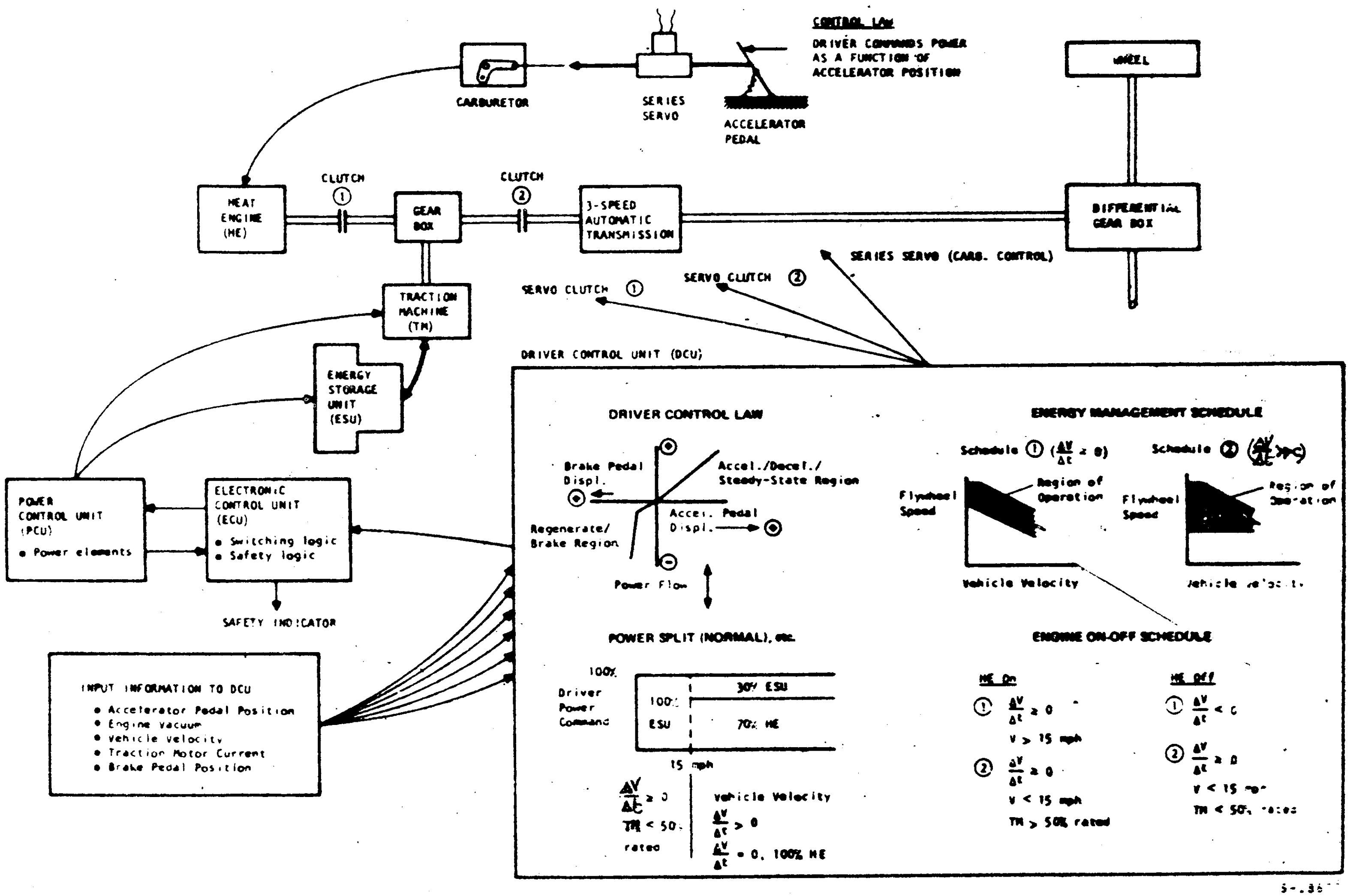


Figure 3 Functional Diagram of Heat Engine/Flywheel Propulsion Configuration (Parallel Electrical Transmission System)

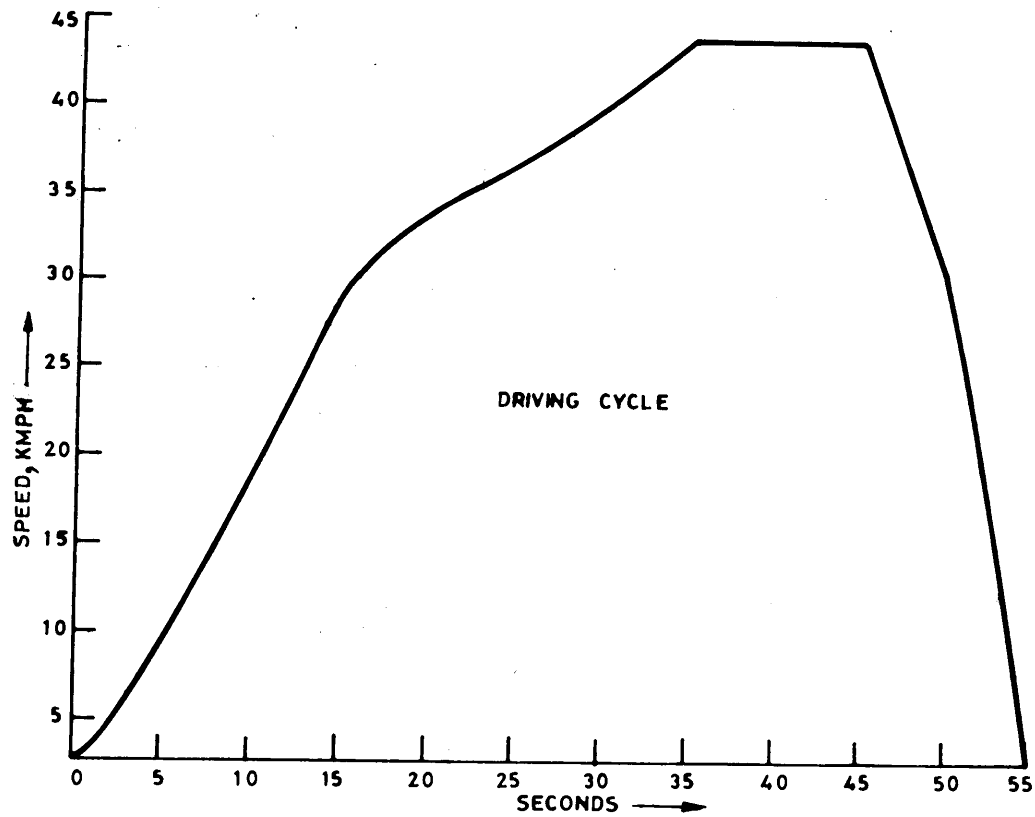


FIG. 4 DRIVING CYCLE

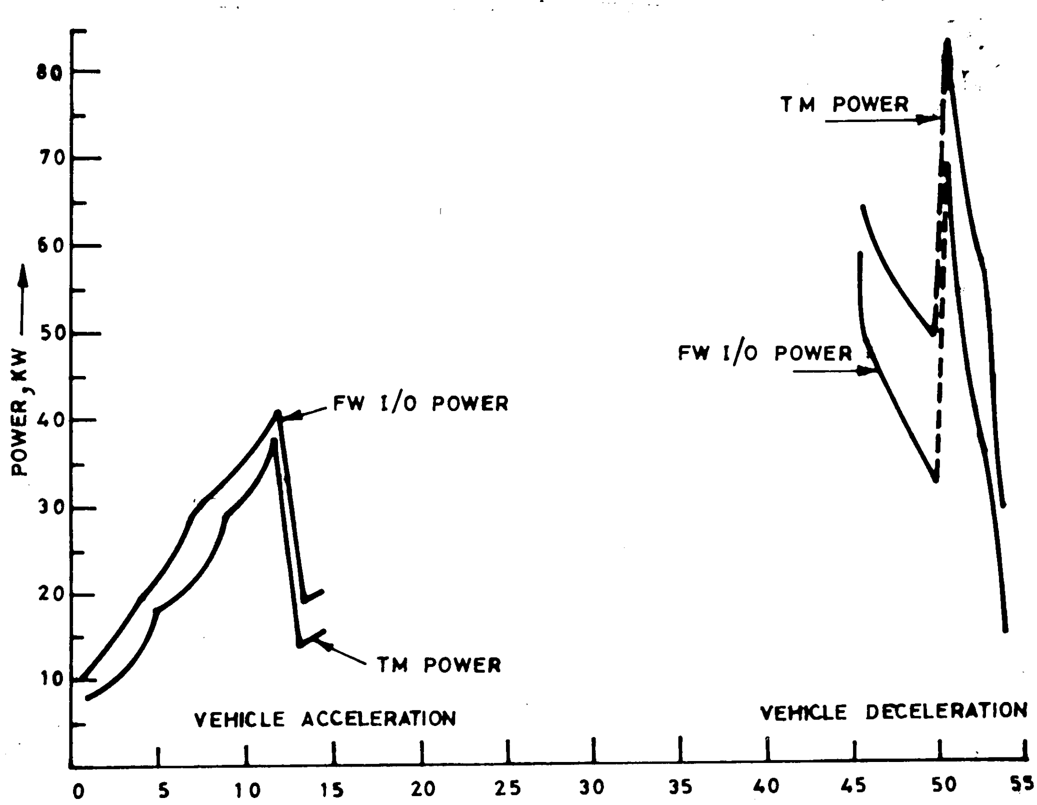


FIG. 5 VARIATION OF TM & FW POWER

"IMPLEMENTATION OF MAINTENANCE PROCEDURES IN OIL/GAS FIRED THERMAL POWER STATIONS FOR OPTIMUM OUTPUT"

AUTHOR

ANIL KUMAR SHARMA; M.E.
DESIGN-ENGINEER
ELECTRICAL CONSTRUCTION COMPANY
(A JOINT VENTURE OF GOVT. OF LIBYA & GOVT. OF INDIA)
TRIPOLI - LIBYA

ABSTRACT

During last few decades a large number of oil/gas fired thermal power stations have come up in oil producing countries. There are so many reasons why these installations do not operate as planned. The main reason is that a viable maintenance system based on local conditions have not been prepared and implemented. In fact establishing of maintenance system in developing countries need another approach than needed in industrialised countries. However certain basic principles of maintenance management can be applied as below:-

- Training of personnel.
- Establishing effective maintenance procedures for different equipments.
- Establishment of various maintenance schedules.
- Monitoring the equipment condition.
- Arrangement of resources such as men, material & tools.
- Preventive maintenance.
- Development of computer based maintenance support system.

Thus in order to ensure optimum output from power stations, "Maintenance" is definitely an area which needs serious consideration.

1.0 INTRODUCTION:

Maintenance may be defined as measures to assure and restore the desired state as well as to determine and assess the momentary status of technical components of system.

No maintenance or inadequate maintenance is the major cause, as per opinion of international experts, for poor performance of thermal power stations erected with heavy investments in developing countries. Most suppliers of plant and equipment often argue that their clients are incompetent or negligent or both and are therefore unable to maintain their machinery properly. This may be true in some cases, but equipment suppliers rarely have any practical experience themselves in the operation and maintenance of the machineries they design.

The real reason in practice for inadequate maintenance is that the programme does not take into consideration the local conditions. Viable maintenance system must be geared up to local conditions in such a way that planned maintenance activities continue after the erectors have left the site.

2.0 LOCAL-SURVEY:

The most important preparatory study is a survey of the conditions in the country or the region where thermal power plants are to be established. The survey includes an indepth study of the following main items:

(i) Climate.

(ii) Site and terrain.

(iii) Transport facilities.

(iv) Power & water supply.

(v) Human resources.

(vi) Market.

(vii) Legal regulations

To examplify the use of survey findings, the importance of "Human resources" will only be discussed.

The skills required to perform various maintenance operations increase with the degree of sophistication of the plant. As such evaluation must include a study of capabilities of the available local technicians. Local trade union activities must also be taken into consideration while composing gangs for maintenance. Some of technicians with special training may regard simple cleaning and lubrication of equipments inferior to their new status. Thus to perform such second line maintenance works it may be necessary to organize special "maintenance squads".

The vital feedback of information after completion of a job requires that the craftman fills in the designated part of the work-order/job-card. In the region

it can only be handled by a supervisor who is called in after a job has been completed.

In the developing oil producing countries the art of management is usually confined to a small group of well trained top managers. Below top management there may be very few candidates with proper background. The supervisory system is often non-existent. Thus implementing a maintenance system required a considerable number of middle-managers will invariably mean their training in both-basic management and job tasks.

3.0 PRE-OPERATION MAINTENANCE PLANNING:

Attention must be paid for separate responsibilities of manufacturer and user. Interface between the two must also be cared as below:

3.1 Manufacturer's Responsibilities:

Following are identified areas where basic design on the part of manufacturer can assist in effective maintenance:-

(i) Provision of boroscope inspection access facilities. For example in case of gas-turbines at such locations as compressor I & II stage, rotor blades and stators, guide vanes & diffusors; combustor; and all turbine stages.

(ii) Provision of continuous vibration monitoring by proximity probes placed alongside all major bearings to detect shaft movements.

(iii) An accurate spare parts list classifying critical and non critical components based on their expected failure rates.

(iv) Providing detailed operation/maintenance manuals and drawings; giving step by step instructions on performing all the scheduled and unscheduled maintenance tasks.

(v) Offer a comprehensive range of tools and test equipments for trouble shooting, repair, adjustment and servicing of plant.

(vi) Provision of Maintainability-Specifications. The information should include weights and centre of gravity locations for major components, required access around and over the equipments, distance between packages and overhead lifting requirements like E.O.T.

3.2 User's - Responsibilities:

These include arrangement of resources like skill-

ed manpower; spares, consumables, general working tools and special tools etc. The following items are to be considered for timely arrangement of resources:-

(i) Training of Personnel:

Local technicians need thorough training before handling the equipments. The training may be divided into four phases :-

(a) General courses held in training centres in basic theory of systems and equipments.

(b) Training of personnel at manufacturer's works.

(c) Training during erection, commissioning and immediately there after at power station.

(d) Training during plant in operation.

(ii) Spares - Arrangement:

To minimise shutdown periods, timely arrangement of spare parts is a must. Special consumable components such as various seals and gaskets, O-rings, fastenings, washers etc. which have to be replaced during every inspection/overhaul should be available always in sufficient numbers. In principle spare parts for 2-3 years should be procured alongwith the plant. Later on stock should be replenished only from the original manufacturer to ensure that spares confirm to specifications and the tests stipulated for special spares are actually carried out.

(iii) Arrangement of Tools & Tackles:

Each maintenance group must be provided with a high quality set of tools needed for normal routine maintenance. Two such sets must be kept aside for emergency needs. Similarly a set of special tools and instruments needed during erection or major overhaul should be kept reserved.

4.0 INPLANT-MAINTENANCE:

Maintenance work as shown in figure (1) consists of :-

(i) Preventive - Maintenance

(ii) After Breakdown Maintenance

4.1 Preventive - Maintenance:

The maintenance department should look upon activities classified as "Preventive Maintenance" as its main duty. Their aim is to keep equipments functional

inspite of inevitable wear and tear by maintaining an adequate margin from the failure limit, known as "deterioration-potential". A potential of 100% corresponds to status following initial commissioning. Repair works can keep the potential upto 100% or even above; For instance by eliminating weak points for which supplier must not necessarily be responsible. Preventive-maintenance can be subdivided in following activities:-

4.2 Inspection:

Daily physical inspection of equipment in operation is a must for maintenance engineer. Various parameters, charts and logsheets, shift-engineer report and defects-register must be thoroughly seen and analysed to chalkout daily maintenance work plan. When some equipment need repair, screening should be done:

a) Whether the machine or its parts are actually repairable?

b) Are repairs the most economical choice? Would replacement be less expensive in long run?

c) How long will the equipment last after it is repaired?

It is impossible to predict accurately when a component has reached its design life. However it is possible to analyse comprehensively the equipment using sophisticated diagnostic information and the experience of trained engineers/metallurgists. Building on that knowledge more sophisticated and advanced inspection techniques are employed. For example in case of gas turbine nozzles distress can appear as visible surface damage or as metallurgical degradation on microscopic level.

Traditional methods of crack detection include penetrant inspection for surface defects and radiography/ultrasonic inspection for internal damage due to creep, fatigue or oxidation. Advanced facilities use specially formulated acid baths, X-ray flourescent and borescopic ultraviolet light inspections to provide a more detailed analysis of nozzle condition. Additionally, metallographic section is taken from the nozzle to determine if the material is weakened by surface attack, over temperature exposure, low cycle fatigue cracks or grain boundry eutectic formations. Most importantly presence of foreign material detrimental to parts integrity and introduced during prior repair may be determined. To assist the evaluation process, metallographic hand books listing micro-structure photos can be used to judge the parts for structural strength and weldability.

4.3 Repairs:

Facilities for carrying out most of the repairs at spot must be arranged in consultation with the supplier,

keeping in view the nature of repairs needed. For example in case of oil/gas fired turbines most often repairing involves nozzles/buckets and combustion hardware since in these areas stress usually appear first.

For repairing many cracks, holes and other defects the welder's art is still used. But it is important to recognize the limitations of welding in today's environment of extended service exposures, machine up rates and higher firing temperatures. Heavy welding in one spot may distort the shape permanently. Also standard weld filler alloys available on open market have demonstrated rapid crack initiation and faster crack propogation compared to various cobalt base super alloys they are used to repair. To minimise second limitation new weld wire alloy like Nozzaloy may be used. Actified diffusion healing (ADH) process may also be employed for vane repair etc. The process uses a mixture of super alloy powders and an organic binder tailored to meet the design requirements of part to be repaired. The mixture melts, solidifies and diffuses when put through a controlled thermal cycle in a vacuum furnace. The process produces a repair with greater strength, ductility,high temperature capability and homogeneous structure. Tests have shown it to produce 33% fewer cracks which are 17% smaller in length than the cracks found in the parent metal.

Repair at manufacturer's works can also be done for costly items and those which can not be repaired at site.

After the parts have been repaired and finished; entire process must be documented. Any advanced repair programme involves one last phase-final inspection. During that stage for example in case of gas-turbine, the turbine is reconstructed and all dimensions are set to original specification. In addition a computer area check and a harmonic analysis should be performed to eliminate possibility of damaging vibrations.

4.4 Interval Between Inspections.

It should be specified in instructions for maintenance by the supplier. For example in gas turbine, material fatigue gets importance after 100,000 hours normal running. Here the main item concerned being the turbine rotor which will then require renewal.

A typical scheduled maintenance interval for turbo machinery is shown in figure II.

5.0 COMPUTERISED MAINTENANCE SUPPORT SYSTEM:

It may be developed in the form of an electronic data processing system as shown in the figure III, namely :-

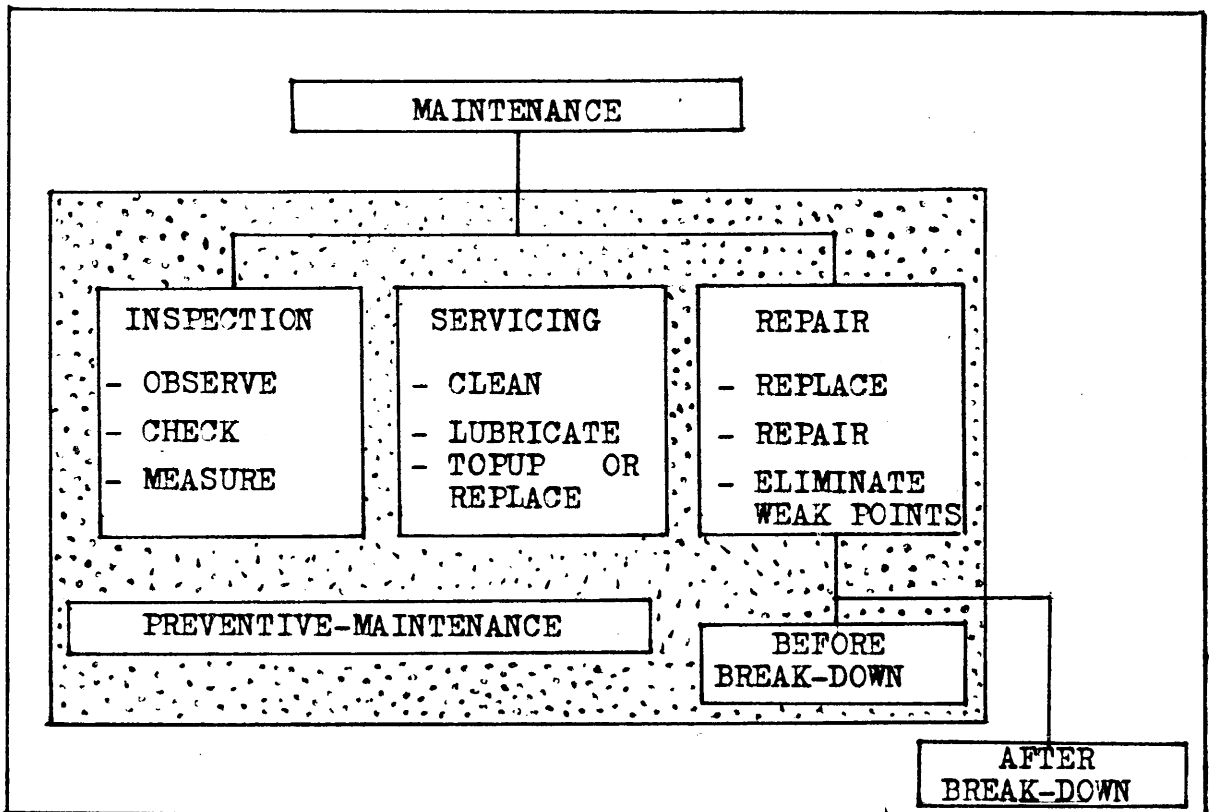


FIGURE - I MAINTENANCE-WORK DETAILS

FIGURE II

Typical Scheduled Maintenance Intervals for Turbo-Machinery

Duty (1) / (2) Environment	Highly Favourable	Favourable	Unfavourable	Highly unfavourable
Continuous	4000 Hrs	3500 Hrs	3000 Hrs	2500 Hrs
Peaking	1500 Hrs	1300 Hrs	1100 Hrs	900 Hrs
Standby	150 Hrs	130 Hrs	110 Hrs	90 Hrs

(1) Duty — Operating Hr/Yr

- Continuous 8000
- Peaking 1500
- Standby 150

(2) Environment

- Highly favourable= Clean /Dry Natural - Gas
- Favourable= No. 2 Diesel Fuel
- Unfavourable= Offshore/natural Gas Lus H2s, Moderate Air Conditions.
- Highly Unfavourable= Offshore/NO. 2 Diesel Fuel, Extreme Cold, Desert, Dusty Conditions.

mely:-

- PMS (Preventive Maintenance System).
- STOCOSY (Stock Control System).

PMS & STOCOSY utilize a micro computer system with video terminals, mass memory & printer etc. Basic data on the products, systems and spare parts from Order Processing System (BAS) of supplier may be transferred. Additional data and texts may also be argumented. Texts and data can be called upon as masks on video terminals or as printouts employing a simple dialogue procedure.

5.1 Special Features of P.M.S.

From manual maintenance plan, basic data stored and current informations on work performed; the following assignments can be called upon:

(a) Deal Line Schedules:

i) They contain tolerances in the data of commencement and completion for a particular job.

ii) Program checking whether a stipulated dead line alternation is admissible.

iii) Incomplete works come on urgent list.

iv) A list of all jobs to be carried out inorder of their planned dates can be called upon.

v) Acknowledgement of completed jobs fed to the system.

(b) Statistics:

i) Hours run by plant facilities per period and totalled.

ii) Fault statistics enabling weak points detection and their elimination.

5.2 Special Features of STOCOSY:

The main functions performed are :

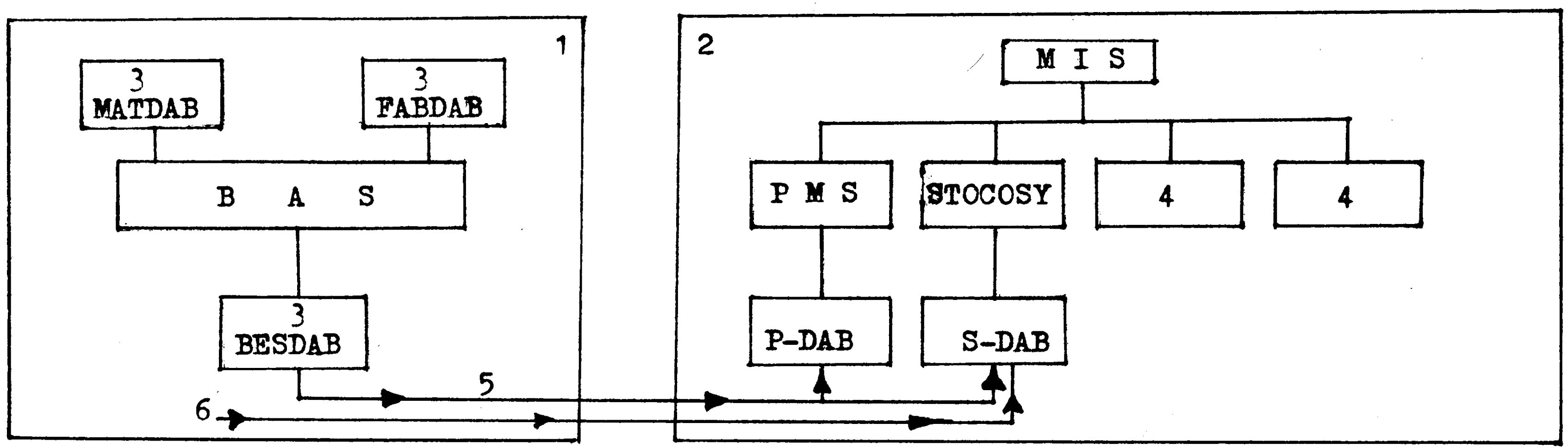
a) To print lables for spare parts bearing a bar code. On issuing a spare, the reading pen attached to a handy portable set reads the bar code and memorizes it. Transfer of memory contents to STOCOSY enables up-keeping of stock list and issue date for particular service order.

b) A certain minimum stock is signalled, enabling a replenishment purchase order timely.

c) Entering new purchase orders and supervise their delivery.

FIGURE - III

Preventive Maintenance System (PMS) and Stock Control System (STOCOSY) as models of Management System (MIS) and links with Order Processing System (BAS) of Supplier



1. System at supplier premises.
3. Data bases:
   MATDAB : Material Data Base.
   FABDAB : Components Data Base.
   BESDAB : Order Data Base.
   P-DAB : Data Base of PMS.
   S-DAB : Data Base of STOCOSY
2. System at User's Premises.
4. Other MIS Modules.
5. Transfer of Contents of Data Bases.
6. Input of Further Information From Supplier.

d) Keeping aside parts for pending servicing jobs.

e) Various evaluations in statistical form to provide major assistance for economic store keeping such as consumption of parts per month / quarter /**year**, spares classification as per consumption rate, annual figures of spares consumption per system, most recent & average purchase prices; inventory maintenance etc.

6.0 CONCLUSION

Preparation of viable maintenance system training, computer aided servicing and store administration enable to maintain the plants properly. In fact repair technology must be constantly evolved to keep with advances in designs and new technology. Only then can be assured of state of art of maintenance as well as balanced economical mix of repair and replacement.

REFERENCES

1. Knauer B.; Maintenance is it **really** " Easy and Simply"? ; M.E.E., April 85 Page 23.
2. Moore Bill; "Gas Turbine Repair: It is not just basic now"; M.E.E. April 85 Pages 32 - 33.
3. G. Gattaneo; "After Sales Services for Cement Industry"; B.B. Review 11-83 Pages 444 to 447.
4. R. Sunkler & Others; Product Support for Gas Turbine; B.B. Review 3/4-83.
5. Chandler A.L. & Champan T.; "Turbo Machinery Maintenance Planning", A.S.M.E. paper 83 -GT - 237 M.E.E. June / July 83.
6. Kelley A.; "Maintenance Planning & Control".
7. W. Fassler; "Availability of BBC Gas Turbines". B.B. Review 66-1070 Pages 130 - 132.
8. BBC Publication DGK 107 981 D.Kraftwork Service.
9. BBC Publication CH. T 050 142 E: "Product Support for Large Turbine Generators".

****

SECTION VI

PROCESS DEVELOPMENT AND POLLUTION

NEW ALGORITHMS FOR HANDLING SYSTEM CONSTRAINTS IN A QUADRATIC PROGRAMMING BASED OPTIMAL POWER FLOW MODEL

J.Nanda
Dept. of Elect.Engg.,
Indian Institute of Technology,Delhi
Hauz Khas,New Delhi-110016,INDIA

D.P.Kothari
Centre for Energy Studies,
Indian Institute of Technology,Delhi
Hauz Khas,New Delhi-110016,INDIA

S.C.Srivastava
Electrical Department
Engineers India Limited,
E.I.House 9th Floor,
New Delhi-110066,India

ABSTRACT:

This paper presents a new algorithm for optimal power flow (O.P.F.) based on quadratic programming (Q.P.) techniques. The algorithm considers two decoupled subproblems seeking for minimum cost of generation and minimum system transmission loss. These have been solved sequentially to achieve optimum allocation of real and reactive power generations and transformer tap settings with due consideration to system operating constraints pertaining to generation, busvoltage, transformer tap and line flow limits. New models for handling system constraints have been developed to suit the Q.P. based O.P.F.algorithm. A maiden attempt has also been made in using a Q.P. method based on quadratic differential principle for solving O.P.F. problem. The potential of the new algorithm for O P.F. has been demonstrated through system studies for two IEEE test systems. Results reveal that the proposed new algorithm has potential for on-line O.P.F. solution.

1. INTRODUCTION

In an optimal power flow problem, total fuel cost and/or total transmission loss or some other appropriate objective functions are minimized subject to the system constraints. A lot of research work has been carried out in the past in the O.P.F. area using several optimization techniques such as classical, linear, quadratic and non-linear programming methods. Amongst them, linear and quadratic programming methods have gained more attention in recent time because of their inherent simplicity, efficient handling of constraints and speed of solution as compared to non-linear programming methods.

Since the two objective functions often used in O.P.F. problem viz. generator fuel cost and total system loss are usually expressed as quadratic functions of real and reactive power generations, it will be worthwhile to use quadratic programming (Q.P.) methods instead of linear programming(L.P.)

which involves additional efforts and approximations in linearizing the objective functions. Further L.P. methods under many situations result in zig-zagging of solution causing convergence problem. In the literature various L.P. based Q.P. methods as developed by Wolfe and Beale [3] are available which have been applied by many researchers for solving only economic load dispatch (E.L.D.) problems. It has been established that the Beale's method is superior to the Wolfe's method. Contaxis et al. [1] are possibly the first to use Q.P. method based on Beale's approach for solving the total O.P.F. problem. They have however, not considered transformer tappings in their model. A Quadratic Differential (Q.D.) Method [3,4] does not require any L.P. subroutine and is found to be superior to the methods developed by Wolfe and Beale. Literature survey shows that the Q.D. method has yet not been applied to power system Q.P.F. problems. The motivation in the present work is to apply the Q.D. method as a maiden attempt to the solution of O.P.F. problem and explore its potential as compared to the Beale's Q.P. method.

The O.P.F. problem considers the twin subproblems of minimizing total fuel cost and total system loss for optimum allocation of active and reactive power generations and transformer tap settings. The algorithm uses a new approach for linearizing various system constraints. New formulations are used to handle the limits on bus voltages, transformer taps and line flows. The two sub-problems have been solved sequentially till both cost of generations and system loss converge to a prespecified tolerance. The potential of the new algorithm for O.P.F. has been demonstrated through system studies on two sample IEEE test systems consisting of 14 and 30 buses. Results clearly demonstrate the superiority of the Q.D. method over L.P. based Q.P. methods to O.P.F. solution.

2. PROBLEM FORMULATION

The O.P.F. problem is decomposed into two subproblems viz optimum real power dispatch (P-optimization) and optimum reactive power dispatch (Q-optimization) subproblems, solved to provide minimum cost of generations and minimum total system real power loss respectively. Exact formulation of system loss [5] has been considered. Consider a system having total N buses and N_L lines. Let the first N_g be the generator buses, the first N_q be the reactive source buses (including the N_g generator buses) and the first N_a lines contain transformers with OLTC control. The two subproblems can be formulated as follows:

2.1 P-Optimization Subproblem

Minimize total cost of generations (F_1) expressed as

$$F_1 = \sum_{i=1}^{N_g} (\tfrac{1}{2}.a_i.PG_i^2 + b_i.PG_i + c_i) \tag{1}$$

subject to

$$\sum_{i=1}^{N_g} (PG_i) - P_L - P_D = 0 \tag{2}$$

and $PG_{imin} \leq PG_i \leq PG_{imax}$ $\quad i=1,\ldots,N_g$ $\quad$ (3)

$I_i \leq I_{imax}$ $\quad i=1,\ldots,N_L$ $\quad$ (4)

where I_i is the magnitude of current in line-i, P_L and P_D are total real power loss and demand in the system.

2.2 Q-Optimization Subproblem

Minimize total system real power loss ($F_2=P_L$) expressed as

$$F_2=P_L=\sum_{j=1}^{N}\sum_{k=1}^{N}\left[\alpha_{jk}(P_jP_k+Q_jQ_k)+\beta_{jk}(Q_jP_k-P_jQ_k)\right] \qquad (5)$$

subject to

$$\sum_{i=1}^{N_q}(QG_i)-Q_L-Q_D=0 \qquad (6)$$

$$QG_{imin} \leq QG_i \leq QG_{imax} \qquad i=1,\ldots,N_q \qquad (7)$$

$$VG_{imin} \leq VG_i \leq VG_{imax} \qquad i=1,\ldots,N_q \text{ (Source buses)} \qquad (8)$$

$$VL_{imin} \leq VL_i \leq VL_{imax} \qquad i=N_q+1,\ldots,N \text{ (Load buses)} \qquad (9)$$

and

$$t_{imin} \leq t_i \leq t_{imax} \qquad i=1,\ldots,N_a \qquad (10)$$

where

$$Q_L=\sum_{j=1}^{N}\sum_{k=1}^{N}\left[\nu_{jk}(P_jP_k+Q_jQ_k)+\xi_{jk}(Q_jP_k-P_jQ_k)\right] \qquad (11)$$

α, β, γ and ξ are loss coefficients computed from bus voltages and bus impedance matrix elements. Q_L and Q_D are total reactive power loss and demand in the system.

Application of quadratic programming will need the objective functions to be in quadratic form of control variables. This can be achieved by considering real and reactive power loads and real generations constant for Q-optimization and omitting the constant terms from Eqs.(1) and (5). In addition Q.P. method needs all constraints to be expressed as linear functions of control variables (control variables to be non-negative). Necessary modifications in the problem formulation are carried out which are described in the following sections:

3.0 HANDLING OF SYSTEM CONSTRAINTS

3.1 Line Flow Limits:

Various techniques are in vogue to consider line flow limits in E.L.D. problem and 'Generalized Generation Distribution Factors'(GGDF) developed byW.Y.Ng [2]are popularly being used in recent works [1]. However, these distribution factors are based on several unrealistic assumptions. Hence a more exact set of New Generalized Generation factors (NGGDFs) are suggested which are computed from base case load flow. These distribution factors (DFs) are used to express line flows (current magnitude) in linear terms of PGs as:

$$I_i=\sum_{j=1}^{N_g}(DF_{ij}.PG_j) \qquad i=1,\ldots,N_L \qquad (12)$$

Thus constraint equation (4) can be rewritten as

$$\sum_{j=1}^{N_q} (DF_{ij} \cdot PG_j) \leq I_{imax} \qquad i=1,\ldots,N_L \tag{13}$$

These DFs are derived directly from the base case load flow results using sensitivity properties of the Jacobian available at the end of the base L.F. and a perturbation technique as described in Ref. [6].

3.2 Bus Voltage Limits

All voltage constraints need to be transformed as linear function of reactive power generations. This can be achieved from the following Q-V decoupled N.R. load flow equations:

$$\begin{bmatrix} \Delta QG \\ \hline \Delta QL \end{bmatrix} = \left[\begin{array}{c|c} A1 & A2 \\ \hline A3 & A4 \end{array}\right] \begin{bmatrix} \Delta VG/VG \\ \hline \Delta VL/VL \end{bmatrix} \tag{14}$$

QG and VG are reactive powers and voltage magnitudes at generator buses and QL and VL are those at load buses. For all practical purposes, system loads are assumed constant for OPF study. Hence $\Delta QL=0$. This provides relationship between change in voltages to change in QGs as follows:

$$[\Delta VG/VG] = [BAJ][\Delta QG] \tag{15}$$

$$[\Delta VL/VL] = [BAB \quad \Delta QG] \tag{16}$$

Substituting these values in Eqs. (7) and (8) and putting $\Delta QG_j^{(k+1)} = QG_j^{(k+1)} - QG_j^{(k)}$, the constraints take the form of

$$VG'_{imin} \leq \sum_{j=1}^{N_q} \left[(BAJ)_{ij} \cdot QG_j^{(k+1)}\right] \leq VG'_{imax} \qquad i=1,\ldots N_q \tag{17}$$

and

$$VL'_{imin} \leq \sum_{j=1}^{N_q} \left[(BAB)_{ij} \cdot QG_j^{(k+1)}\right] \leq VL'_{imax} \qquad i=N_q+1,\ldots,N \tag{18}$$

where VG'_{imin}, VG'_{imax}, VL'_{imin} and VL'_{imax} are computed at the end of k^{th} iteration and can be considered as constant for $(k+1)^{th}$ iteration.

3.3 Limits on Transformer Taps

A new approach of handling the transformer tap settings in the proposed Q.P. algorithm is envisaged. The main concept lies in the fact that if the additional reactive power injection needed to maintain the voltage of a bus being controlled by OLTC is known, desired tap setting value can be back-calculated.

Consider an ith transformer in the system connected between buses-j and k having a series admittance $Bser_i$ ($Bser_i$ for transformer is negative) and negligible shunt admittances. Bus-j being at higher voltage level than bus k, the OLTC is provided on bus-j side, which controls the voltage at the bus-k to reflect necessary change in transformer tap setting previously set at $a_i=a_i^{(o)}$ where $a_i=1/t_i$.

If the reactive power dispatch solution provides a reactive power generation at bus-k as QG_k to maintain its voltage level within limits and at the same time minimizes transmission loss, then this can be considered as being met by changing transformer tap setting from its old value $a_i^{(o)}$ to the required new value $a_i^{(n)}$ (say). The reactive power support (QG_k) needed to bus-k will be provided in the form of change in reactive power flow from bus-j to k due to change in transformer tappings. This provides the value of new tap settings as:

$$a_i^{(n)}=1/t_i^{(n)} = \frac{QG_k}{V_j V_k \ Bser_i \cos(\delta_j-\delta_k)} + a_i^{(o)} \tag{19}$$

The limits on fictitious reactive power generations are derived from Eq.(19) as follows:

$$QG_{kmax}=((1/t_{imax})-(1/t_i^{(o)})).V_j.V_k.Bser_i.\cos(\delta_j-\delta_k) \tag{20}$$

$$QG_{kmin}=((1/t_{imin})-(1/t_i^{(o)}))V_j.V_k.Bser_i.\cos(\delta_j-\delta_k) \tag{21}$$

A case may arise when the bus-k being controlled by transformer OLTC happens to be an actual Q-source bus (generator bus). The reactive power dispatch problem can be solved by considering only a single Q-source with its reactive power generation capability fixed considering the combined capabilities of the generating units and the fictitious Q-source to OLTC. The required reactive power generations on such buses can utilize the reactive power capability of the generating unit first, followed by OLTC only when the reactive power required at a bus exceeds the capability of the generating unit at that bus.

3.4 Equality Constraints

The equality constraints are nonlinear in terms of bus voltages and powers and need to be expressed as linear function of control variables. This can be achieved by partially differentiating active power balance equation (2) with respect to PGs and reactive power balance equation with respect to QGs and arranging them in difference form. For (k+1)th iteration the linearized equation constraints can be written as:

$$\sum_{i=1}^{N_g} PH_i.PG_i^{(k+1)} = K_1 \ \text{(constant)} \tag{22}$$

and

$$\sum_{i=1}^{NQ} QH_i.QG_i^{(k+1)} = K_2 \ \text{(constant)} \tag{23}$$

where $PH_i=\left[1-\partial P_L/\partial PG_i\right]^{(k)}$, $QH_i=\left(1-\frac{\partial Q_L}{\partial QG_i}\right)^{(k)}$

$$K_1= \sum_{i=1}^{N_g} (PH_i.PG_i^{(k)}). \qquad K_2 = \sum_{i=1}^{NQ} (QH_i.\ QG_i^{(k)}),$$

$NQ=N_q+Na-NC$ and Nc= Number of buses having generators as well as OLTC provisions.

3.5 Positivity Conditions of Variables

Variables (PG^s) in P-optimization always assume positive values, but variables (QG^s) in Q-optimization can be negative under leading power factor mode. Hence QG^s cannot be taken directly, as the Q.P. method needs all variables to be non-negative. This can be circumvented by defining a new set of variables Qg^s as follows:

$$Qg_i = (QG_i - QG_{imin}) \qquad i=1,\ldots,N_Q \tag{24}$$

All equations are modified in terms of new variables Q_g^s.

Final algorithm of the OPF problem is achieved by embedding all the modifications suggested above. The two subproblems (P-optimization and Q-optimization) are solved sequentially followed by a load flow at the end of each iteration till both total cost of generations and system real power loss converge to a prespecified tolerance.

4. SYSTEM STUDIES

System studies have been carried out on IEEE-14 bus and 30 bus systems. The results are obtained on an ICL-2960 computer with convergence criteria of 0.0001 p.u., 0.1\$/hr and 0.001 p.u. for power mismatches, cost of generations and total system loss respectively on a 100 MVA base. The generator bus voltages are allowed to vary between 1.0 p.u. and 1.1.p.u. whereas load bus voltages are constrained between 0.9 p.u. and 1.1 p.u. The transformer tapping are allowed to vary from 0.95 p.u. to 1.05 p.u. ($\pm$5%). Four case studies were conducted on both the systems using the quadratic differential method and Beale's Q.P. method and the results are presented in Tables -1 and 2. These detailed studies were carried out in order to examine the effect of accounting the varying degree of constraints on OPF result and the comparative performance of the two Q.P. methods used.

In case study-1, the OPF results have been obtained considering the limits on real and reactive power generations, bus voltages and the two power balance equations. Case study-2 was conducted to consider the effect of accounting for transformer taps on the OPF results which were allowed to vary continuously within the range selected. Literature survey shows that probably no researcher has considered discrete OLTC settings in OPF studies. Hence a more realistic situation in case study-3 has been simulated by considering discrete OLTC settings in steps of 2.5%

After each optimization iteration, the optimum tap settings found are approximated to their nearest discrete tap values and used in subsequent iterations. Other limits considered in case sutdies-2 and 3 are same as in case study-1. Case study-4 considers all constraints of case study-3 alongwith line flow constraint. $NGGDF^s$ were obtained using 1% perturbation in PG^s from base load flow and kept constant during optimization iterations.

Table-1: IEEE-14 Bus System O.P.F. Results

Method used	Case study	Cost of generations ($/hr)	Total system real power loss, PL (MW)	No.of Opt. iterations/ load flows (excluding base LF)	CPU time in secs.for complete OPF excluding base LF.
1	2	3	4	5	6
-	Base case	1156.394	11.70	-	-
Quadratic Differential Method	Case-1	1135.478	8.94	4	30.4
	Case-2	1134.654	8.89	8	69.6
	Case-3	1134.760	8.90	8	70.0
	Case-4	1134.796	8.92	8	70.4
Beale's Q.P. Method	Case-1	1135.959	9.22	5	38.70
	Case-2	1135.460	8.78	8	74.70
	Case-3	1135.579	8.81	9	85.50
	Case-4	1135.948	9.18	9	92.34

Table-2: IEEE-30 Bus System O.P.F. Results

Method used	Case study	Cost of generations ($/hr)	Total system real power loss, PL (MW)	No.of Opt. iterations/ load flows (excluding base L.F.)	CPU time in secs for complete OPF excluding base LF.
1	2	3	4	5	6
-	Base Case	1288.281	15.38	-	-
Quadratic Differential Method	Case-1	1244.932	10.40	4	68.80
	Case-2	1244.009	10.19	7	128.10
	Case-3	1243.928	10.17	8	166.00
	Case-4	1245.464	10.46	8	171.60
Beale's Q.P. Method	Case-1	1245.310	10.51	6	108.24
	Case-2	1244.527	10.36	8	169.72
	Case-3	1244.268	10.29	9	193.50
	Case-4	1246.435	10.81	9	215.64

The results (Tables 1 and 2) reveal that tremendous reductions in system loss and cost from their base case values is achieved in all case studies either by using Q.D. method or the Beale's Q.P. method. The Q.D. method, however, has provided better cost and loss figures in all case studies and has provided faster solution as compared to the time taken by the Beale's Q.P.method.

5. CONCLUSIONS

i) The models developed for applying Q.P. methods to optimal power flow problem use new formulations to account for transformer taps, voltage constraints and linearization of equality

constraints. A more exact set of 'New Genralized Generation Distribution Factors' to account for line flow constraints is suggested and used for optimal power dispatch problem. Transformer tap settings have been considered in discrete steps for the first time. Formulations of various system constraints are found to be working effectively. Inclusion of OLTC in the mathematical model, however, increases the number of iterations for solution.

ii) **Optimal loadflow** problem has been solved for the first time using quadratic differential method. Significant reduction in cost and loss figures are achieved by either the QD or the Beale's method. Quadratic differential method, however, provides better cost and loss figures and much faster solution than the Beale's method. Thus the quadratic differential method is more suitable for on-line optimal power flow solution.

6. REFERENCES

[1] Contaxis, G.C., Delkis, C., and Korres, G., "Decoupled Optimal Load Flow using Linear or Quadratic Programming", IEEE Trans., 1986, PWRS-1, pp.1-7.

[2] Ng, Wai Y., "Generalized Generation Distribution Factors for Power System Security Analysis", IEEE Trans., 1981 PAS-100, pp.1001-1005.

[3] Wilde, D.J., and Beightler, C.S., Foundation of Optimization, Prentice Hall Publication, 1967.

[4] Kuester, J.L., and Mize, J.H., Optimization Techniques with Fortran, McGraw Hill Inc., New York, 1973

[5] Elgerd, O.I., Electric Energy Systems Theory - An Introduction, McGraw Hill Inc., New York, 1971.

[6] Srivastava, S.C., "On Some Aspects of Load Flow and Optimal Load Flow of Interconnected Power Systems", Ph.D. Thesis, I.I.T. Delhi, India, 1987.

USE OF GASOLINE-WATER MIXTURES IN A SPARK IGNITION ENGINE TO CONTROL NITRIC OXIDE EMISSION FROM EXHAUST GAS

DR. N.S. MURTHY*
MECH. ENGG. DEPT.
HIGHER INSTITUTE OF
MECH. & ELEC. ENGG.
HOON, LIBYA.

1. ABSTRACT

An algorithm has been developed for solving the equations for the analyses of the thermodynamic cycle and for the rate of NO formation inside the cylinder of a 4-stroke spark ignition engine working on petrol-water mixtures and it has been implemented on a computer. Experiments were conducted on a 4-cylinder automobile engine using petrol-water mixtures. Three different methods of introducing water along with the fuel have been employed. Performance and emission characteristics of the engine have been investigated with different amounts of water added to the fuel and at different operating conditions. The theoretical results showed acceptable quantitative agreement with the experimental data.

2. NOMENCLATURE

α	coefficient of excess air
ϵ	compression ratio
η_v	volumetric efficiency
γ	residual gas fraction
θ	crank angle at which heat release starts
β	index used in the expression for the heat release curve
n	index used in the expression for the heat release curve
λ	ratio of crank radius to the length of the connecting rod
N	engine speed in revolutions per minute
C_f	fraction of carbon in fuel
H_f	fraction of hydrogen in fuel
H.V	heating value
M_-	molecular weight of fuel

Professor (on leave)*
Mech. Engg. Dept.,
Indian Institute of Technology
KHARAGPUR, INDIA

L_o stoichiometric moles of air
T^s temperature of the surrounding
P_s pressure of the surrounding

3. INTRODUCTION

Rapid growth of automobiles as a means of transport has led to a tremendous increase in the emissions of toxic pollutants into the atmosphere, especially in urban areas. The significant toxic components emitted through the I.C.Engine exhaust gases are : Carbon Monoxide (CO), unburnt hydrocarbons ($C_n H_m$) and oxides of nitrogen (NO_x). As regards the reduction of the three major toxic components from the I.C. Engine exhaust gases, experiments show that among these three major components, NO poses the greatest difficulty. Most of the methods used for reducing NO emissions invariably decrease the fuel economy. Though a number of investigations have been carried out, the process of NO formation inside the cylinder of an engine is not yet fully understood. Hence it becomes difficult to find out an effective method for reducing NO emission without sacrificing economy. Since it was found very difficult to study the process of formation of NO inside the engine cylinder experimentally, investigators have resorted in the recent past to the use of theoretical models to study the process.

Measured NO content in the exhaust does not correspond to the values calculated using chemical equilibrium (it is a non-equilibrium process). Hence it is difficult to predict quantitative NO content using chemical equilibrium calculations.

Formation of NO in the engine cylinder depends not only on the various operating parameters, but also on the character of the combustion process, which in turn depends on the design and other factors.

4. THEORY

Analysis of thermodynamic cycle closer to the actual cycle and of the theoretical model for NO formation have been made. In the analysis of the thermodynamic cycle, heat addition process closest to the real process, variable specific heats, dissociation of the products of combustion are taken into account. Chemical equilibrium composition for the products of combustion and the temperature distribution inside the combustion chamber are considered.

Heat release curve is assumed. This curve can be compared with the actual heat release curve which can be obtained from the experimentally determined indicator diagram. S-shaped curve suggested in the work [1] is found to be more satisfactory and has been assumed. It is expressed as follows :

$$x = 1 - \left[1 - \left(\frac{\psi + \theta}{\psi_{comb}} \right)^{\beta} \right]^{n} \qquad \text{.. (1)}$$

where x = fraction of the fuel burnt
ψ = crank angle
θ = start of combustion before TDC, °C.A.
ψ_{comb} = duration combustion

n and β are the indices which govern the intensity of heat release.

It is assumed that (i) the closed cycle under consideration consists of real working substance whose mass remains constant throughout the cycle but varies in composition. The working substance has actual specific heats depending on the temperatures. The closed cycle consists of polytropic compression, combustion, expansion of products of combustion taking into account heat of recombination and heat rejection at constant volume. Heat transfer across the walls is taken into consideration during polytropic compression. (ii) The entire charge is divided into an arbitrary number of portions of equal mass. The temperature in each portion remains constant though it varies from portion to portion. (iii) Pressure in all the portions is the same. (iv) Products of combustion consist of the following components : CO, CO_2, H_2O, H_2, H, OH, O, O_2 and N_2. (v) Products of combustion in each zone are in chemical equilibrium at every moment. (vi) There is no heat transfer across the walls and among the zones, except during the compression process during which heat transfer from walls is approximately taken into account. (vii) The working mixture is homogeneous and contains air, fuel vapour, residual and recirculated gases.

Equations of state for ideal gas are used in cycle calculations. Equilibrium reaction constants are taken from the tables from literature.

The pressure at any moment in the cycle can be calculated by the following formula given by B.S.Stechkin [2]

$$\frac{k-1}{A} V^{k-1}\, dQ = d(pV^k) \qquad \text{.. (2)}$$

where p = momentary pressure
V = momentary volume
Q = heat supplied
k = ratio of specific heats, C_p/C_v
A = 1/427

The basic differential equation (2) is numerically solved by second order Runga-Kutta method. Integration is done at an interval of 1°C.A. Considering mass balance and energy balance, calculation of temperatures and equilibrium compositions of the products of combustion in each zone is done by the method of successive approximations.

The following chain reactions for NO formation, as indicated in the works of Zeldovich [3] and Lavoie [4] have been used for the determination of rate of NO formation in each isolated zone of the charge.

1) $N_2 + O \rightleftharpoons NO + N$
2) $O_2 + N \rightleftharpoons NO + O$
3) $N + O \rightleftharpoons NO$
4) $N + OH \rightleftharpoons NO + H$
5) $N_2 + O_2 \rightleftharpoons 2NO$

Reaction 4 has a significant contribution to the overall NO formation as emphasized by many authors including Anand [5] in their investigations based on two zone models. According to V.A. Zvonow [6] the parallel occurance of the bimolecular reaction 5 along with the basic mechanism also leads to an increase in the overall NO emission. Due to less concentrations of N and O in the products of combustion and large reaction (rate) constant for this reaction, we may not expect much significance of the reaction-3.

Momentary concentrations of NO in the concerned portion of the products of combustion are determined by solving the kinetic differential equation for the process of NO formation

$$\frac{d(NO)}{dT} = f([NO], [M_j][T_z]) \qquad .. (3)$$

where T = time in seconds
M_j = molecular weight
T_z = temperature in °K in the zone

Reactions 1 to 4 are interdependent. Hence rate of NO formation can be determined as the summation of rates of NO formation from the 4 reactions and the rate of NO formation by reaction-5.

Thus

$$W_{NO(1-5)} = W_{NO(1-4)} + W_{NO(5)}$$

Rate of NO formation $W_{NO(5)}$, is found out from the formula

$$W_{NO(5)} = 2 \left[K_5[N_2]_e[O_2]_e[-K_5'][NO]^2 \right]$$

where the quantities in brackets signify the concentrations of the individual components and K_5 and K_5' are forward and reverse rate constants respectively for the reaction-5. Suffix 'e' signifise equilibrium value.

The kinetic differential equation (3) of NO formation is solved by Runga-Kutta method (of second order) taking an interval of 1°C.A.

5. EXPERIMENTAL SET-UP

The experimental set-up consisted of a 4-cylinder automobile engine (whose specifications are given below) fitted with various accessories to get the desired variation of parameters. A D.C. Electric Dynamometer of 150 K.W. (at maximum speed of 6000 r.p.m.) is used. A rotameter RS-150 is used for air-flow

consumption. ir consumption is recorded with the help of a concentric disc attached to the rotor of the rotameter, a photo-cell and an electronic digital counter ESA-3. Fuel and water flow rate is measured by noting the time for consuming a known volume of fuel with the help of burettes. Engine speed is measured with the help of a digital revolution counter. A graduated disc mounted at one end of the crankshaft, a reference pointer and a stroboscope are used for measurement of spark-timing. A thermocouple and a potentiometer are used to measure the exhaust gas temperature.

CO and CO_2 concentrations in exhaust gas are measured by automatic gas analysers OA-2109 and OA-2209. HC concentrations are measured with the help of gas chromatograph (LCHM-8MD) with flame-ionisation detector (FID). NO concentrations are measured with the help of photo-colorimeter using Saltzman technique.

6. PROCEDURE

For calculating the theoretical results of kinetic NO formation and the temperature variations inside the cylinder, the following parameters are varied.

(1) Water added to the fuel
(2) The duration of combustion and the temperature at the beginning of the compression process (T_a). The data kept constant for the calculation is shown in the following table.

α	= 1.07	N	= 2000
ϵ	= 8.5	C_f	= 0.855
η_v	= 0.86	H_f	= 0.145
γ	= 0.70	H.V	= 10400
θ	= 15.00	M_f	= 115.0
β	= 2.5	L_o	= 0.512
n	= 2.5	T_s	= 293
λ	= 0.278	P_s	= 1.00

While experimenting, three methods are employed for injecting water into the cylinder. In the first method water is injected into the individual inlet manifolds, near to the inlet ports and the flow through each manifold is adjusted to be equal. In the second method, water is injected into the venturi of the carburetor and in the third method, water is introduced through ultrasonic diffuser provided over the air filter.

7. GENERAL TEST PROCEDURE

After switching on all the test equipment, the engine is started with no load. The engine is run till the cooling water and lubricating oil temperatures attain the set temperatures. When the cooling water and lubricating oil temperatures remain steady, the load on the engine is gradually increased. Flow rates of fuel and air are adjusted till the engine is supplied with the required air fuel ratio mixture. After adjusting all the parameters to the desired values, the readings of all the measuring instruments are noted. Simultaneously, samples of exhaust gas are collected into evacuated pipettes for analysis

of HC and NO concentrations whereas CO and CO_2 concentrations are directly measured by passing the exhaust gases through the instrument.

8. RESULTS AND DISCUSSION

Kinetic NO formation and temperature variation inside the cylinder in 1st, 5th and 10th zones with 20% water added to the fuel (T_a = 360°) is shown in Fig.1. The same trends of variation are noticed with 10% and 30% water added to the fuel and with different inlet temperatures. The trends of variation are similar to the trends observed while using pure gasoline.

Effect of addition of water to the fuel on average NO emission, maximum temperature in the initial zone of combustion and cycle efficiency is shown in Fig.2. All these three parameters decrease gradually (almost linearly) with the increase of the amount of water.

Effect of temperature at the beginning of compression (T_a) on average NO emission, maximum temperature in the initial zone of combustion and cycle efficiency is shown in Fig.3. Both average NO emission and the maximum temperature in the initial zone of combustion increase with an increase in the value of T_a whereas the cycle efficiency decreases.

All the three methods of water addition to the fuel (viz. introducing water into the individual intake manifolds through nozzles fitted close to the inlet ports, introducing water through an additional jet provided inside the venturi of the carburettor, introducing water through an ultrasonic diffuser provided over the air filter) gave almost identical results.

Water addition upto 45% resulted in reduction of NO_x emissions. As shown in Fig.4, greater reductions occured at leaner mixtures. At α = 1.05 about 60% reduction in NO_x emission is observed. However, water addition has little effect on HC and CO emissions.

Optimum spark timing has to be advanced with water addition Power output decreased and b.s.f.c. increased with water addition. The decrease in power output and increase in b.s.f.c. are almost identical with 30% and 45% water addition.

With 30% water and using an ultrasonic diffuser, the fuel economy is improved compared to pure gasoline operation (Fig.5.)

Increasing spark advance resulted in an increase in NO_x emission and a decrease in b.s.f.c. Effect of HC emission is negligible (Fig.6).

9. CONCLUSIONS

1. In a homogeneous charge, maximum quantity of NO is formed in the initial zone of the combustion products, having the maximum temperature. In many cases NO concentration in the initial zone attains maximum equilibrium

value and then docomposes during expansion process. The rate of NO formation in the middle and the last portions of the charge is less and the concentrations do not attain the maximum equilibrium values.

2. The trends of variation of kinetic NO formation and temperature inside the cylinder, with different quantities of water injected into the intake manifold are similar to the trends observed while using pure gasoline.

3. Increasing the amount of water injected, decreased (i) average NO emission (ii) maximum temperature in the initial zone of combustion and (iii) cycle efficiency.

4. Increasing the temperature at the beginning of the compression, increased (i) average NO emission (ii) maximum temperature in the initial zone of combustion whereas the cycle efficiency is decreased.

5. Different methods of introducing water along with the fuel viz. (i) injecting water into the intake manifold (ii) injecting water into the venturi of the carburettor and (iii) use of an ultrasonic diffuser provided over the air filter, gave almost identical results.

6. Water addition decreased the power output and increased the brake specific fuel consumption. However, the effect on HC and CO emission was negligible.

7. With 30% water and using an ultrasonic diffuser, the fuel economy is improved compared to pure gasoline operation.

10. REFERENCES

[1] Efremov B.D., Chernyak, B.Y., "Mathematical model of heat release process in Internal Combustion Engines", Publication No. 96 of MADI, Moscow 1975.

[2] Stechkin, B.S., "Engine Indicator Diagram and Heat Release Process", Proceedings of Scientific and Technical conference on Combustion and Mixture Formation in I.C. Engines. Publication AN USSR 1960.

[3] Zeldovich, Y.B., Sadovaikov, P.Y., Frank Eamenetshi,D.A. "Oxidation of Nitrogen during combustion", Publication AN USSR, M 1947.

[4] Lavoie G.A., Heywood, J.B., Kock, J.C., "Experimental and Theoretical Study of Nitric Oxide Formation in I.C. Engines", Comb. Sci. and Techn. 1970, VI, 313-326.

[5.] Annand W.J.D., "Effects of Simplifying Kinetic Assumptions in Calculation of Nitric Oxide Formation in Spark Ignition Engines" Proceedings of Instn. of Mech. Engrs. v 188 41/74

[6] Zvonow, V.A., "Toxic Emissions from Internal Combustion Engines" Published by 'Machinostraveniye'.

[7] "Modelling and Simulation to Predict Kinetic NO Formation Inside the Cylinder of a Spark Ignition Engine" - Paper Presented at International Conference on Modelling and Simulation Held at Istanbul, Turkey, June 28 to July 1, 1988. Author - N.S. Murthy.

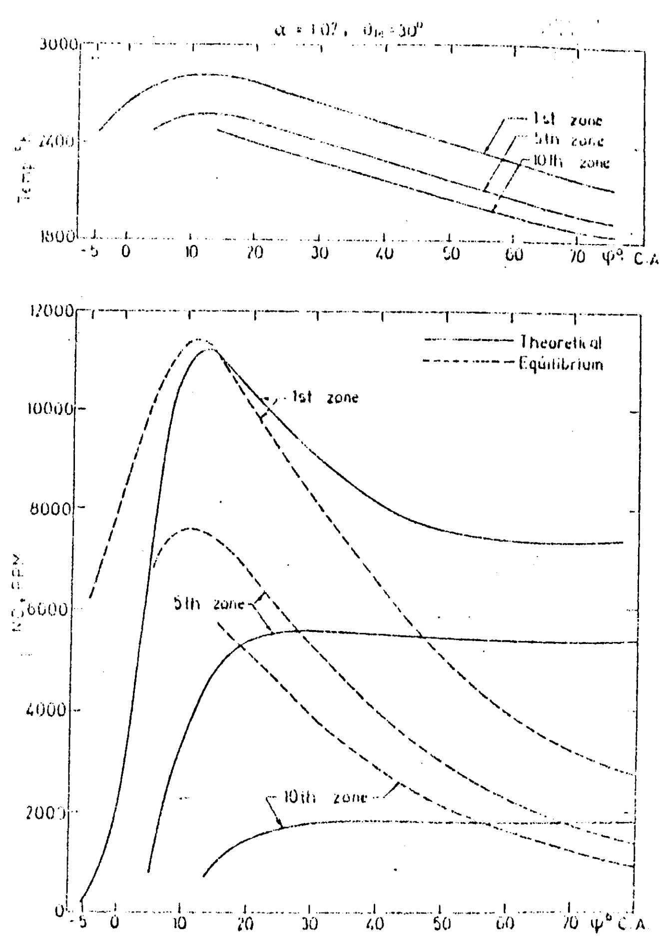


Fig. 1 Kinetic NO formation and temperature variation inside the cylinder with 20% water added to the fuel ($T_a = 360^0$ K)

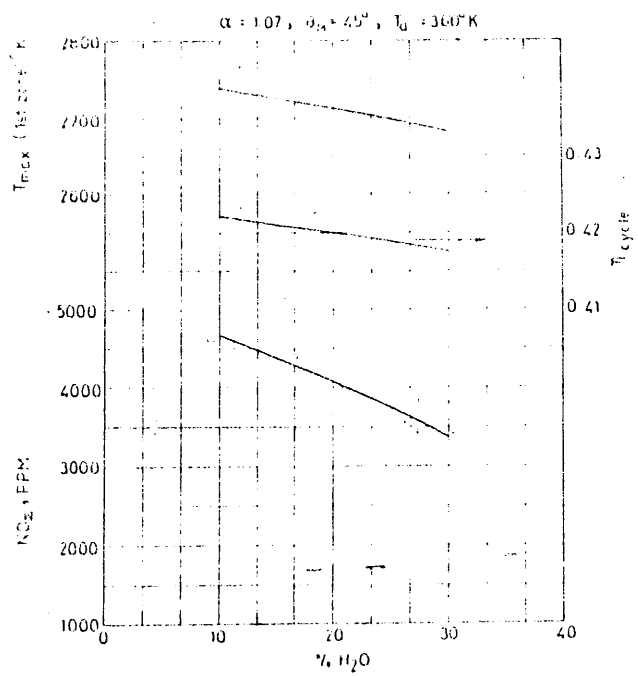


Fig. 2 Effect of addition of water to the fuel on performance and emission characteristics (Theoretical)

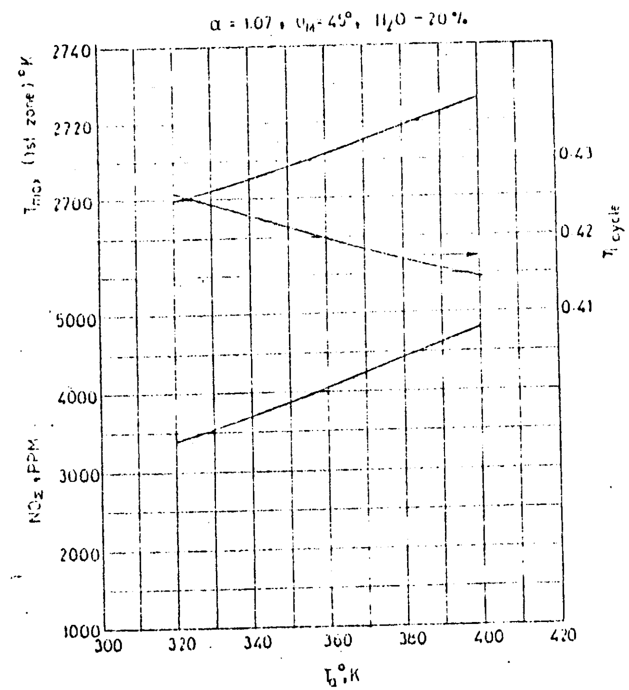


Fig. 3 Effect of temperature at the begining of compression on performance and emission characteristics (Theoretical)

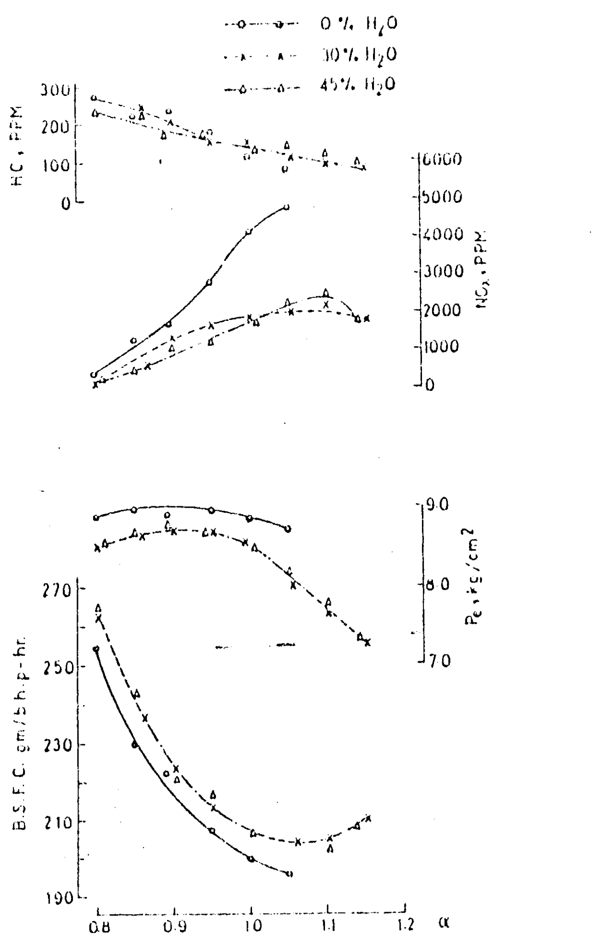


Fig 4 Effect of water addition to the fuel on the performance and emission characteristics (contd)
N = 2000 R.P.M., $\eta_v = \eta_{v\,max}$, Spark advance (θ) - Optimum

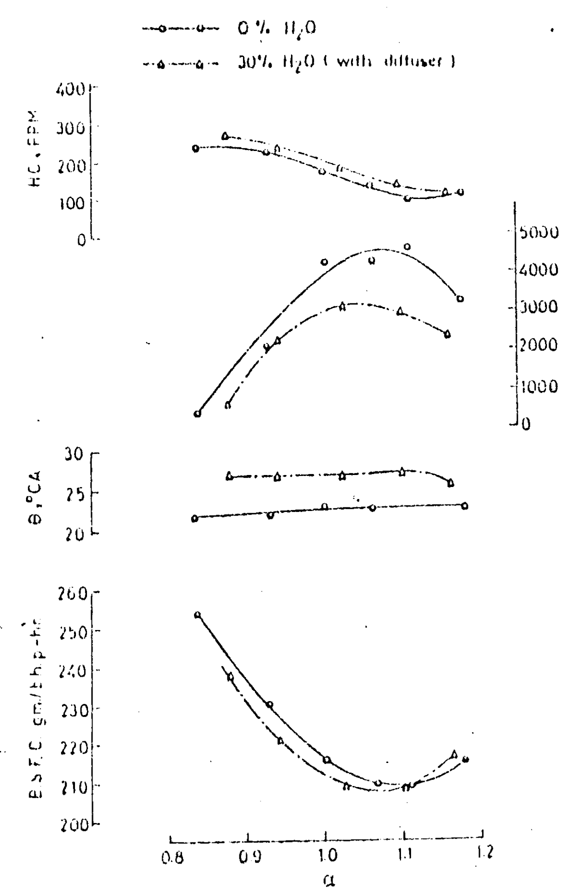


Fig. 5 Effect of water addition to the fuel using an ultrasonic diffuser on the performance and emission characteristics
N = 2000 R.P.M., $P_e = 0.8\,P_{e\,max}$, Fuel - 70 O.N.,
Spark advance (θ) - Optimum.

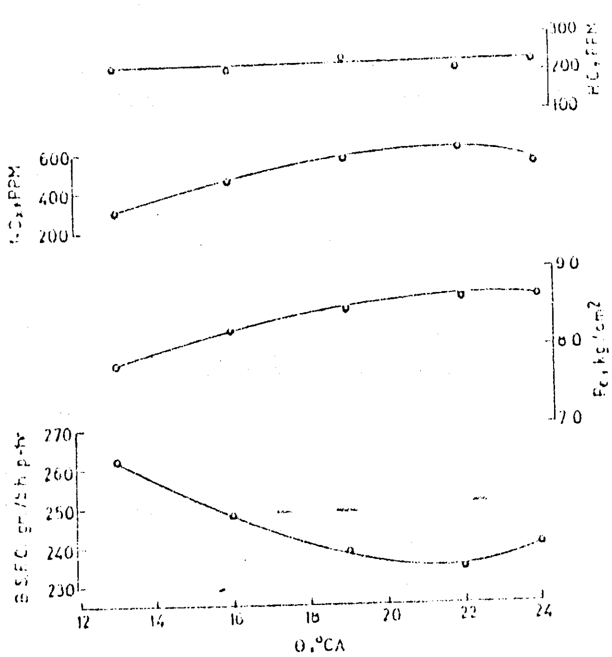


Fig. 6 Performance and emission characteristics versus spark advance.
$N = 2000$ RPM, $\eta_v = \eta_{v\,max}$, $\alpha = 0.85$,
30 % H_2O added to 70 O.N. fuel

ENVIRONMENTAL POLLUTION CAUSED BY FOSSIL FUEL AND BENEFITS DUE TO TRANSFORMATION TO SOLAR HYDROGEN ENERGY SYSTEM FOR A LIBYAN COMMUNITY

WIDAD B. ELOSTA
CENTRE FOR SOLAR ENERGY STUDIES
TRIPOLI, LIBYA

ABSTRACT

The combustion products of fossil fuels are causing growing damage to our planet, through pollution, acid rains and the greenhouse effect. Harmfull fossil fuel combustion products are carbon monoxide(CO), Sulphur Oxides (SO_x Total Suspended Particulates(TSP), Oxides of Nitrogen(NO_x) Reactive Organic Gases(ROG), Photochemical Oxidents(O_x) and Lead. All these pollutants and the diseases that caused or aggravated by these toxins could be eliminated by converting to hydrogen system.

A mathematical model had been developed for a Libyan Community. The adverse impact of these environmental pollutants on our quality of life and on our economy as well as the big improvements and health benefits of converting to a solar-hydrogen energy system had been studied.

INTRODUCTION

Almost all the energy demand is met by fossil fuels. The fact that fossil fuel resources are limited everywhere, besides the big damage that they cause to human beings, animals and plants, led the scientists everywhere to look for more than a decade, for other energy alternatives that are renewable and more compatible with environment.

In this paper, it is proposed to apply the solar hydrogen energy system for a Libyan community and compare the pollution level and the quality of life before and after the application of this system. The environmental damage due to fossil fuel consumption and its saving due to the utilization of hydrogen system are also examined and emphasised.

1. ENVIRONMENTAL PROBLEMS

It was estimated that during the year 1983 [1] *, the fossil fuel produced 25 billion tons of primary pollutants CO_2, CO, NO_x, SO_2, O_3, Soot and Ash. It is estimated that for each gallon of gasolin consumed $1.00 must be expressed from health care budget for pollution related illness [2] .

* Figures in square brackets refer to references at the end of the paper.

1.1 Environmental Effect on Humans

Pollutants derived from fossil fuel consumption are harmful and have an adverse effect on human health. CO reacts with hemoglobin and affects the brain, the kidneys, the central nervous and might cause a stroke and a heart attack as well [3] . Leaded gasolin caused bone growth problems in children and elevated blood pressure in adults [4] . Gasoline vapours might have a damaging effects on the brain [1, 5] . SO_x can cause irritation of the respiratory system. Total solid particu lates(TSP) can cause deleterious effects on the linings of the nose, sinuses, throat and lungs. It can also cause tissue destruction and cancer [6] .

1.2 Environmental Effects On Agricultural Lands and Forest Resources

High concentration of Lead(Pb), Cadmium(Cd), and Zinc(Zn) caused by motor vehicles contaminate roadside grass and vegetation and cause extensive damage to this vegetation [7] . Concentration of these metals in plants depends on trafic density, distance from trafic and direction of wind.

The destructive effect of pollution on forests takes longer time than that for crops.

1.3 Environmental Effects On Animals

All the animals are also affected indirectly by pollution through the lack of food or the excess acidity of drinking water in lakes and streams.

1.4 Environmental Effects On Buildings

The acidity of precipitation in many parts of the world has been steadily increasing over the past few decades [8] . The increasing Sulfur and Nitrogen oxides in the atmosphere, emitted by power plants factories and road vehicles, is believed to be responsible for this phenomenon. When acid rain falls, some places in the world are badly affected.

1.5 Environmental Effects On Fresh Water Sources and Fish Resources

Acid rain reaches fresh water sources and lakes, the PH factor of the water falls. So the water would be unsuitable for human consumption as potable water. Also the lakes would be fishless.

2. GREEN HOUSE EFFECT

Fossil fuel consumption always adds CO_2 to the atmosphere. CO_2 now constitutes about 334 ppm of the atmosphere, while in pre-industrial times it was less than 290 ppm. So today the level of CO_2 is about 14 percent higher than that of the pre-industrial base and it is expected to be 30 percent higher than the pre-industrial base by the year 2000 [9] .

CO_2 is not considered a pollutant, but it plays an important role in the determination of the global climate. The presence of CO_2 in the atmosphere produces a "green-house effect". It is believed that the greenhouse effect is responsible for the global warming trend that could raise the average temperature between 2°F and 8°F by the year 2050 [10] . This warming trend would shift deserts toward the north and south and consequently would shrink the size of agricultural lands,

so people migration, famine, death and other social effects may also occur. Also the greenhouse effect is responsible for the rise in the sea level. This is caused by the melting of polar glaciers and ice caps It is estimated that the sea level rise rate is 10-14 mm per year [1] .

3. OZONE DEPLETION

The threat to the ozone depletion first discovered in 1983. Ozone (O_3) is a form of Oxygen. It is created when solar ultraviolet rays strikes oxygen molecules(O_2) in the atmosphere. It protects the earth's surface from the penetration of harmful rays. Ozone can be destroyed by many chemical processes.

When ozone is destroyed, more harmful ultraviolet radiation would be allowed to strike the earth. Ultraviolet radiation is a form of light invisible to the human eye. It causes sunburn and skin cancer. Also it weakens the immune system in human beings. So oxygen screens out these harmful rays and prevents such kinds of sickness. It is estimated that a one percent drop in ozone level would cause about 10,000 cases of skin cancer a year [10] .

4. SOLAR HYDROGEN ENERGY SYSTEM FOR A LIBYAN COMMUNITY

El-Charabulli lies about 63 Km east of Tripoli. Its population is 46,900 and energy consumption is 3.30×10^6 Gj. Petroleum and natural gas are used for the different kinds of energy applications. A model has been developed for this community. In this model different parameters have been studied to show the effect of introducing a solar hydrogen energy system in reducing pollution levels and increasing the standard of living. The solar hydrogen energy system will hopefully be introduced by the year 1995 with hydrogen production to meet 5 percent of the total energy demand and direct electricity from PV also to meet 5 percent of energy demand. Thereafter, hydrogen production would increase steadily year by year and the fossil fuel consumption will decrease until the solar hydrogen energy system would be able to meet the total energy demand for the community. It is expected that photovoltaics will be built in the southern parts of the community, since large areas of land unsuitable for farming at the present time are available.

It is assumed that ten percent of the electricity from photovoltaics(PV) would be used during the day for domestic, commercial, aggricultural and industrial demands for the community. The rest of the electricity(90 percent) would be used through electrolyzers in the hydrogen plants to electrolyze water into hydrogen and oxygen. Part of this hydrogen would be used to produce electricity through fuel cells, which would represent about 15 percent of the total energy demand. This electricity would be used for energy demand during the night, early morning and cloudy days. The rest of the hydrogen(which would represent 75% of the total energy demand) would be distributed equally between transportation, industry, and domestic and commercial sectors.

Hydrogen combustion will cause little pollution, or no pollution at all if combustion temperatures are limited or oxygen is used instead of air for the combustion. Hydrogen could be used in every application in which fossil fuels are used. It would never be depleted, since the water used to produce hydrogen is replaced when it is consumed.

5. POLLUTION

The amount of pollution depends on the amount and type of fuel

consumed, either fossil fuel and/or hydrogen. Before the introduction of the solar hydrogen energy system, the equation for pollution can be expressed as:

$$P_n = U\,(F_n) \tag{1}$$

Where P_n : The amount of pollution produced at time t_n.

U : The pollution units per energy unit.

F_n : Fossil fuel consumption at year t_n.

After the solar hydrogen energy system introduction, the pollution can be expressed by the following equation, considering negligible pollution from the PV.

$$P_n = U\,(F_n + \varepsilon H_n) \tag{2}$$

Where ε is the ratio of the pollution produced by hydrogen per energy unit of hydrogen to that produced by fossil fuels per energy unit.

The pollution ratio is defined as the ratio of the pollution at time t_n, to that of the initial time.

$$P_{rn} = P_n/P_o \tag{3}$$

6. BENEFITS DUE TO SOLAR HYDROGEN ENERGY SYSTEM

One of our aims in this model for El-Gharabulli community is to show the effect of creating a hydrogen community on reducing the air pollution level and subsequently saving on health care costs. It is estimated that the total environmental damage of the fossil fuels is $8.26/GJ [11] . So, if no hydrogen was introduced, the environmental damage cost would be

$$D_{en} = E_n\,C_p \tag{4}$$

Where D_{en} : The cost of total environmental damage at year t_n.

E_n : Energy consumption at year t_n

C_p : The environmental damage price per energy unit.

After hydrogen introduction, the cost of environmental damage would decrease, and it can be re-expressed as:

$$D_{hn} = (F_n + \varepsilon H_n)\,C_p \tag{5}$$

Where D_{hn} : The cost of total damage caused by hydrogen and fossil fuel at year t_n.

F_n : Fossil fuel consumption at year t_n.

: The ratio of pollution produced by hydrogen to that produced by fossil fuels.

The saving in environmental damage can be defined as the difference between the environmental damage cost caused by fossil fuel, when no hydrogen is introduced and the environmental damage cost when

hydrogen is utilized for the community. The equation for saving in environmental damage, S_{pn}, can be expressed as

$$S_{pn} = D_{en} - D_{hn} \tag{6}$$

7. QUALITY OF LIFE

The quality of life would increase with increase of gross production. But it will decrease with increase of pollution. Considering the above parameters, the quality of life can be expressed as

$$L_n = G_{rn}/(Q_{rn} \cdot P_{rn}) \tag{7}$$

where L_n : Quality of life at year t_n.

G_{rn} : Gross production at year t_n.

Q_{rn} : Population at year t_n.

P_{rn} : Pollution at year t_n.

8. RESULTS AND DISCUSSION

A computer program has been developed to study the different parameters in the model for different rates of hydrogen introduction (θ_h). Figure (1) represents the pollution ratio P_r, *vs.* time T. It is clear from this figure that if no hydrogen is introduced the pollution will be six times what it was in the initial year 1985 around the year 2060 and it will remain constant thereafter. For the other rates of hydrogen introduction, the pollution ratio will drop to 0.195 by the year 2085 in the case of slow rate of hydrogen introduction and to 0.177 by the year 2045 in the case of faster rate, then slowly rises to 0.23 or 23 percent of its 1985 value. This slight increase in pollution which is about 5.3 percent for the last case is due to the slight increase in hydrogen energy consumption. Since the pollution effect, in the case of hydrogen utilization (about 4 percent that of fossil fuels) is considered to be minor, mostly nitrogen oxides, we see the pollution increase in these curves is very small.

In Figure (2) , it can be seen how the quality of life drops to 0.52 by the year 2045 if there is no hydrogen and it remains almost constant after that while the quality of life ratio will increase to about 17.98 times its initial value in 1985 for other rates of hydrogen introduction.

Figure (3) , represents the environmental damage due to fuel consumption, D_h Vs time, T. In the case of no hydrogen introduction we see that the environmental damage increases exponentially to a value of $\$165 \times 10^6$ per year by the year 2081 and remains almost constant thereafter. When a hydrogen energy system is introduced the environmental damage decreases to a negligble value as the hydrogen production dominates the total energy consumption.

The difference between the environmental damage with no hydrogen introduction case and with three different cases of hydrogen introduction, shown in Figure (3) gives the savings in environmental damage due to hydrogen energy system utilization, S_p, which is shown in Figure (4) .

9. CONCLUSION

It could be concluded that air pollution from fossil fuel combustion is a serious global public health problem. Hydrogen evolves as a leading, cleaner, universal fuel resource. The application of solar hydrogen energy system for the community would reduce the pollution rate, improve the quality of life and leads to a big savings in environmental damage. Therefore, this system would lead to a healthier and happier community.

References

1. Awad, A. H & Veziroglu, T. N. "Hydrogen Versus Synthetic Fossil Fuels", Int J. of Hydrogen Energy, Vol. 9, No. 5, PP 355, 366, Pergamon Press, Briton, 1984.
2. Zweig, R. M., "Health Benefits Derived From A Planned Hydrogen Community, in T. N. Veziroglu (ed.), Hydrogen Energy System. Proceedings of the 2nd World Hydrogen Energy Conference, Zurich, Switzerland, August 21-24, 1978, Vol. 4, Pergamon Press.
3. Zweig, Robert M., "Hydrogen-Prime Candidate for Solving Air Pollution Problems", in T. N. Veziroglu, W. D. Vorst, & J. H. Kelly (eds.), Hydrogen Energy Progress IV, Proceedings of the 4th World Hydrogen Energy Conference, Cal. U.S.A., June 13-17, Vol. 4, Pergamon Press, 1982.
4. Sweig, R. M., "Health Benefits of A chinese Hydrogen Economy", Int. J. of Hydrogen Energy, Vol. 12, No. 4, PP 267-270, Pergamon Press, Briton, 1987.
5. Pihl, R. O., "Lead, Cadmium Linked to Learning Problems". Science News., Vol. 112, 1977.
6. Train, Russel E., "Enviornmental Cancer"., U.S. Environmental Protection Agency, Washington D.C., Vol. 195, No. 4277, Science(2-4), 1977.
7. Fytianos, K., Vasilikiotis, G., & Samanidou, V., "Contamination of Roadside Vegetables with Lead, Cadmium & Zinc", Chemosphere, Vol.14 No.314, PP 271 - 277, 1985, Great Briton. Pergamon Press, 1985.
8. "Effects of Ozone and Sulfur Dioxide on Tomato". Energy and Technology Review., Lawrance Livermore National Laboratories, July 1985.
9. Daniel Rich, et al., "The Solar - Energy Transition, Implementation and Policy Implementations, " Westview Press, Inc., 1983.
10. "The Heat Is On", TIME, October 19, 1987, No. 42.
11. Veziroglu, T. N., Progress and Problems in Hydrogen Technology Re-Energy Needs of Human Settlements.

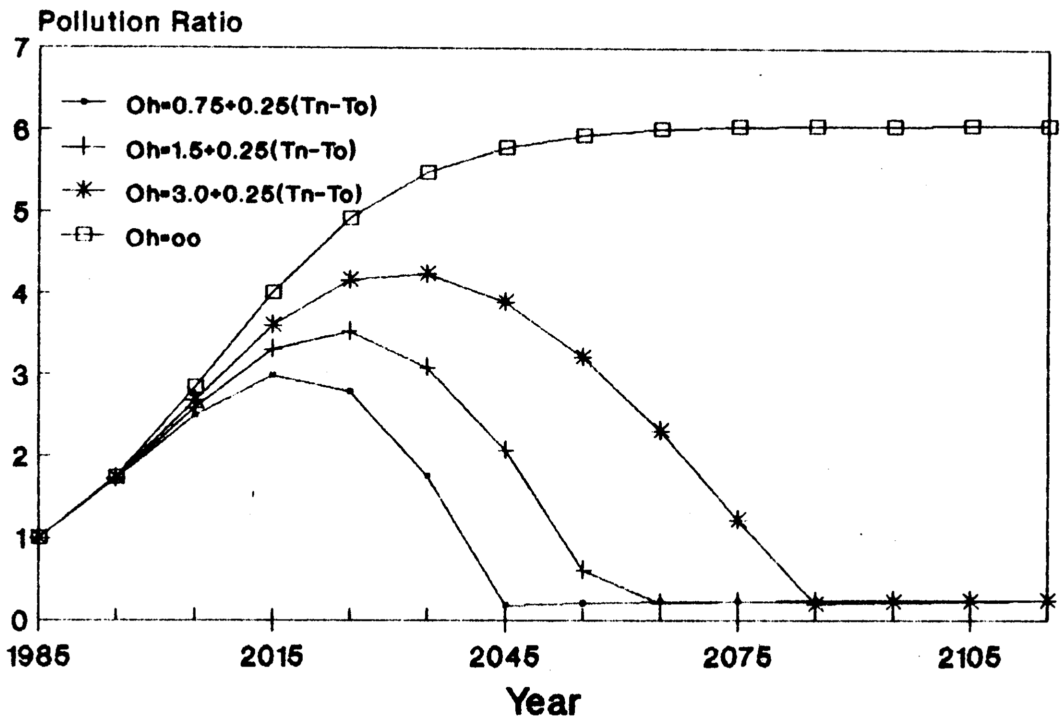


Figure:1 .Pollution Ratio vs.Time

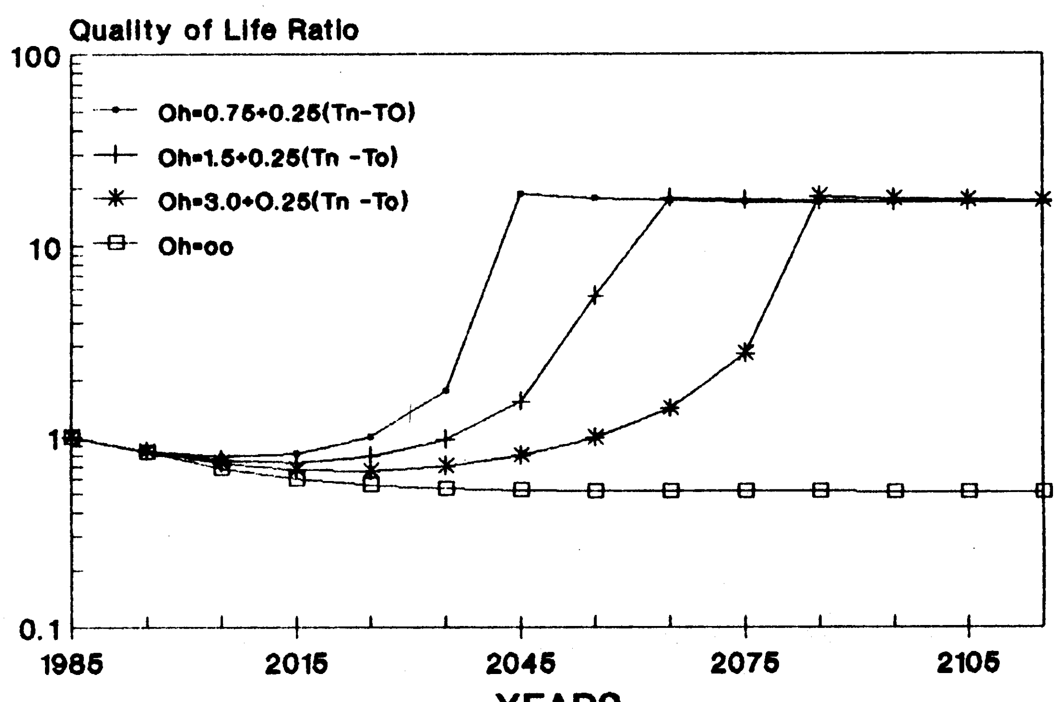


Figure: 2 .Quality of Life Ratio vs.Time

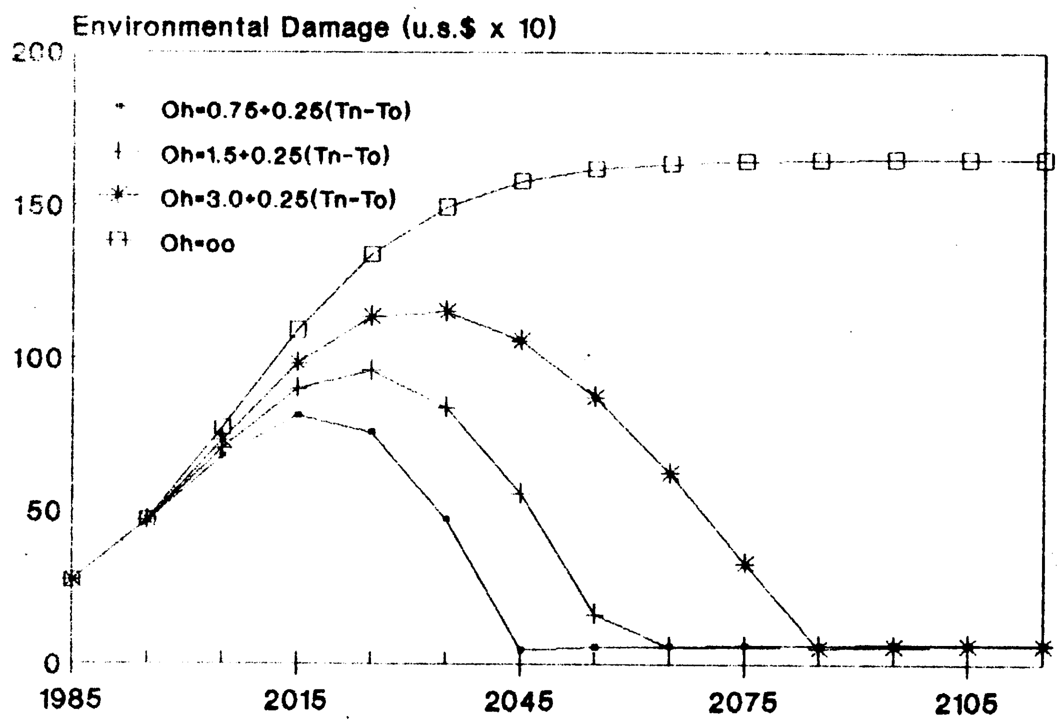


Figure:3.Environmental Damage.

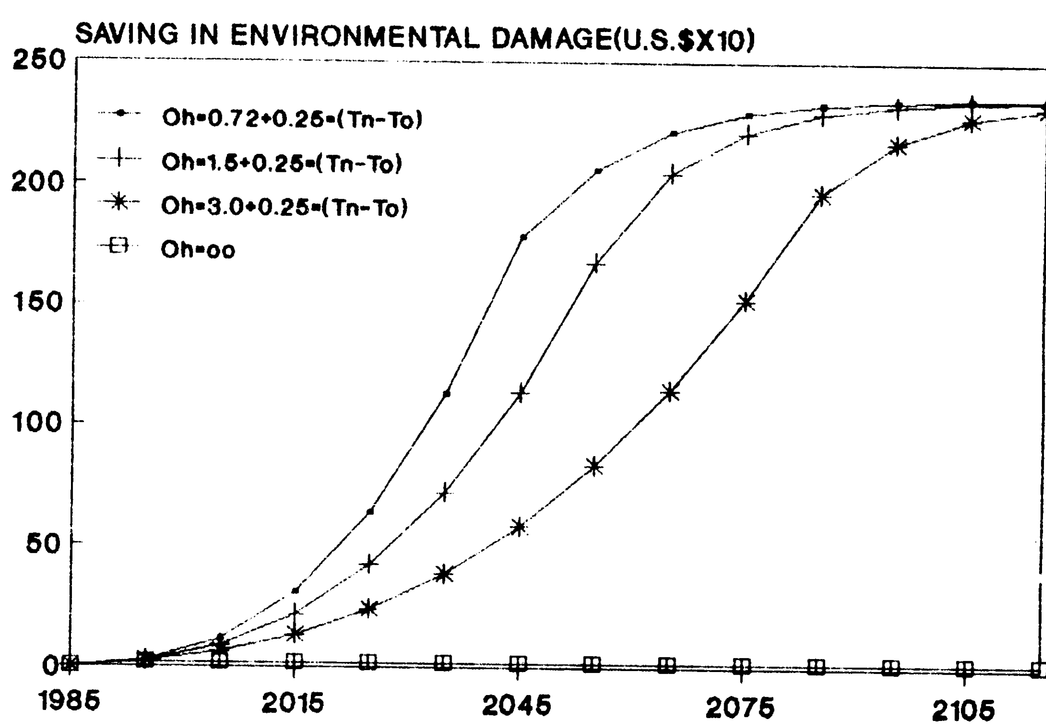


FIGURE :4.saving in Environmental Damag

ENVIRONMENTAL IMPACT FROM H.A.R

UPGRADING PROJECT

Dr. G. DROGARIS
Asprofos Engineering S.A.
El. Venizelou Ave. 50,
GR-176 71 KALLITHEA
GREECE

1. ABSTRACT

Hellenic Aspropyrgos Refinery (H.A.R.) is the oldest and biggest greek refinery located in Aspropyrgos, 17 km from Athens. The Greek Government decided in 1982 to proceed with the modernization of H.A.R. by adding conversion units in order to achieve a compatitive operation of this state owned refinery. In the course of the so called "H.A.R. Upgrading Project" 15 new process and 13 new utility units have been installed in H.A.R. under the project management of Asprofos Engineering. The main restriction during the design evolution stage of the subject project has been imposed by Environmental constrains, since the grate Athens area is suffering by severe environmental pollution problems.

Therefore the installation of the new refinery units should conform to tight environmental restrictions without jeopardizing the feasibility of the project.

Satisfactory solution of this problem has been achieved by Asprofos Process Department by integrating, in the most effective way, the best available environmental abatement technology in the upgraded refinery operation scheme in order to meet client and authorities requirements.

It is the intention of this presentation to describe briefly the environmental abatement measures taken for H.A.R. and their significance and to show that competitive operation of a modern conversion refinery may be combined with compliance to the most severe environmental constrains provided that due consideration has been payed during the early design phase.

2. AIR EMISSIONS ABATEMENT

The most important air pollution sources from a refinery are furnace and boiler stacks and storage and transfer operation of hydrocarbons. Air pollution abatement measures can be divided in two categories :

a) Installation of new environmentally bound process units.

b) Design features contributing to reduction in pollutants emissions.

2.1 New Environmentally Bound Process Units

Fig. 1 shows the integration of the new "environmental" units in the overall refinery process scheme. In addition to the normally considered as environmentally bound units (i.e. a MEA Wash unit, a Sour Water Stripper unit and a Sulphur Recovery unit) a Low Pressure Hydrocracker unit (IFP process) has been installed. This unit practically desulphurizes VGO to be fed to the FCC unit (FCC feedstock will contain 0.15-0.3%wt sulphur only). Simultaneously, by variation of the operating conditions, this unit may cause either hydrotreating only or both hydrotreating and mild hydrocraking (for partial middle distillates production) to the VGO. Hence refinery has the flexibility to increase either gasoline or diesel oil production and consequently to match easier seasonal variations in oil products demand.

2.2 Design Features Leading To Environment Protection

A full description of all design features considered can not be presented in the course of a brief presentation. Generally the environmental measures fully cover the most of the international requirements for refinery operation as for example those valid in U.S.A., U.K. and F.R.G. [1,2,3]. Following an indicative list is given :

a) The new environmentally bound process units (MEA Wash unit, Sour Water Stripper and Sulphur Recovery units) have been designed in two parallel trains, so that even in case of failure in one of these units the operation of the refinery (either at slightly reduced capacity or using crude with a lower sulphur content) can be continued without any adverse effect on the environment.

b) All gaseous byproducts from cracking operations (FCC, hydrocracking, visbreaking) are routed to a gas consentration unit for LPG recovery. The remaining fuel gas can then be washed in the MEA unit and consequently fuel gas used by the refinery is practically free from sulphur compounds (H_2S : less than 50 ppm).

c) Sulphur produced is degassed for H_2S removal. Solid sulphur is prilled and transferred and stored in close circuit/silos in order dust emissions to be eliminated. Further delivery of liquid sulphur to fertilizer factories is possible, which will lead in energy saving in sulphur user factories.

d) The height of new stacks (main stack 120m, SRU incinerator 60m) has be selected so that pollutants ground level concentrations to be minimized. In addition a design flue gas exit velocity of 15m/s has been considered to assure that no downwash entrainment of flue gas could occur.

e) Sour Water Stripper overhead gas is routed to the Sulphur Recovery Unit. This stream will be fed to dedicate burners due to NH_3 content.

f) Seal water from new and existing flares is routed to the Sour Water Stripper Unit.

g) FCC regenerator is designed for low CO emissions and three stages of cyclones have been foreseen for catalyst particles removal.

h) All new and existing floating roof tanks are equipped with liquid primary seal and secondary seal. All new and existing fixed roof tanks will be equipped with pressure/vacuum vents.

i) All safety valves releasing gases (except steam) and sampling points of LPG storage area are connected to the flare. All safety valves releasing liquid (except water) are connected to close systems (e.g. tanks, pumps suction etc.). A dedicated close drain system for MEA Wash and Sour Water Stripper units has been also foreseen.

j) Existing furnace and boilers having relatively low stacks (15-40m) will be preferentially fired on practically sulphur free fuel gas.

k) Steam generation in waste heat boilers will be extensively performed.

l) Low NOx burners have been installed in all new furnaces.

m) The new API-separator is designed with four channels for storm conditions but normally only one channel is in operation. The other three are put automatically in operation in case of storm. Further to and forth travelling skimming bridges have been installed.

2.3 Results

Though the overall fuel consumption after implementation of the Upgrading Project will be almost increased by a factor of 2 compared with the hydroskimming operation of H.A.R. the SO_2 emissions will be reduced by nearly 30%. This is attributed to the extensive use of sulphur free fuel gas, the installation of thenew Sulphur Recovery Unit with a recovery efficiency of at least 99%, the use of low sulphur (0.7%wt S) fuel oil and the extensive use of waste heat boilers.

The environmental benefit is even higher due to the better dispersion achieved since low existing stacks have negligible SO_2 emissions and the main stack has a height of 120m. Almost 60% of total SO_2 is emitted from the new main stack but the maximum SO_2 ground level concentrations due to this main stack is expected to be in the range of 5 to 10g/m³ (on daily basis). The maximum SO_2 ground level concentration due to refinery operation on a daily basis is estimated to be about 27g/m³ under the worst atmospheric conditions. Hence expected SO_2 ground level concentrations due to refinery operation represent only :

- 5-10% of the U.S.A. ambient air quality standards.
- 8,5-17,5% of the W.H.O. ambient air quality standards.

The maximum NOx ground level concentrations due to refinery operation on an hourly basis is expected not to exceed 50g/m³ under the worst atmospheric conditions and represent only :

- 25% of the EEC ambient air quality standard.
- 15-26% of the WHO ambient air quality standard.

Finally hydrocarbons emissions marginal reduction (in the range of 10%) is expected though new process units and storage tanks are installed as result of the measures described in paragraph 2.2 above. The VOC fugitive emissions are estimated to be in the range of 0,04% of the processed crude, which is satisfactory [4].

3. LIQUID EMISSIONS ABATEMENT

The overall effluent collection, treatment and reuse scheme is given in figure 2.

The liquid emissions abatement measures can be also divided in two categories :

a) Installation of new environmentally bound units.

b) Design features contributing to reduction in pollutants emissions.

3.1 New units

The new waste water treatment unit, shown schematically in figure 3, is designed for 70kg BOD_5/h organic load and has a net hydraulic capacity of 200m^3/h. The process selected is the most common used in european conversion refineries [5] and is in agreement with the requirements of the german authority for water protection for the erection and operation of refineries [6]. The unit consists of :

a) Primary treatment (API-separator for primary deoiling, equalization, pH adjustment and secondary deoiling in an IAF unit).

b) Secondary treatment (first step : biological trickling filter, second step : extended aeration activated sludge designed also for nitrification, clarifier).

c) Tertiary treatment (sand filtration).

d) Sludge treatment (primary sludge deoiling, thickening and dewatering in belt presses).

Ballast water is treated separately in a dedicated line (100m^3/h capacity) consisting of primary deoiling (PPI-separator), secondary deoiling (IAF unit) and dual media filtration. The effluents from the dimersol unit contain some Ni in the form of a complex salt used as catalyst. This effluent is treated in dedicated treatment unit (steam stripping for NH_3 removal, oxidation and precipitation by means of H_2SO_4 and dewatering in chamber filter press) for Ni removal before it is routed to the inlet of the Waste Water Treatment Plant.

Further dedicated API-separator has been installed for possible TEL contaminated drainages (TEL blending, leaded products storage and loading areas).

3.2 Other Measures

In addition to the units described in paragraph 3.1 above all other measures normally required for refineries [1,2,3] have been also foreseen. The most important are briefly highlighted herebelow :

a) The API-separator has been designed to cope with a storm having a 95% cumulative occurrence probability (i.e. once every 20 years). Stormwater after being primary deoiled are stored and bleed-off later at the inlet of the Waste Water Treatment Plant.

b) The existing open sea water cooling system will be replaced by a closed cooling water circuit. A cooling tower with a design capacity of 15.000m^3/h has been installed.

c) Barometric condensers of the existing Vacuum Distillation Unit will be replaced by surface condensers, resulting in tremendous reduction in waste water flowrate.

d) There are available all necessary equipment and materials (such as boat, floating seals, skimmer, approved chemicals etc.) for fighting immediately any accidental oil spillage to the sea.

e) In case of accidental oil contamination of the cooling water system (e.g. due to leackage from a cooler) cooling water blowdown can be diverted to the ballast water tanks and then treated in the ballast water treatment line.

f) As shown in figure 2 aqueous effluents have been segregated and treated separately and reused to the maximum possible extent mainly :

- In the desalters (preferentially use of phenolic stripped sour waters).
- In the service water network.
- In the firefighting network.

Further the reuse of final effluent as cooling tower make-up has been investigated and might be implemented after getting some experience in the operation of the cooling tower.

3.3 Results

Mainly due to the change of the cooling water system a reduction in the order of magnitude of 95% will be achieved in the waste water flow to the sea. Consequently a substantial reduction in the pollution load(mainly BOD_5 and suspended solids and to a lesser degree phenols and ammonia) will be also achieved.

A comparison of H.A.R. with other refineries worldwide (see tables 1 and 2) shows that H.A.R. should be considered as one of the most environmentally sensitive refineries regarding aqueous effluents. It should be noted that the five german refineries referred to in the attached tables are located in the same area (within 10km around Ingolstadt) and sent their effluents to the same river. Due to this location extremely severe regulations have been applied ($BOD_5 < 25$mg/1, phenols<0.2mg/1,oil<3mg/1 etc).

4. SOLID WASTES

In addition to the normal refinery solid wastes (mainly sludges from tanks and spent catalysts) sludge from the waste water will be added due to the Upgrading Project. This sludge being deoiled and dewatered can be easily disposed of by landfill.

5. NOISE

The noise level specification of 85dB (A) 1m apart from the noise source has been applied in the Project. This results in noise level at refinery fence substantially lower than the current valid regulations in Greece.

6. ENERGY CONSUMPTION

The old H.A.R. was importing as an average 5.1 MW from the Public Power Corporation grid. After implementation of the Upgrading Project the electric power import will be reduced to 0.5-1 MW though the electric

power consumption will be increased by a factor of almost four, mainly due to the installation of a combined cycle gas turbine. The cost of electric power from the gas turbine is estimated to be about 50% lower than the price of the imported electric energy from PPC grid.

7. NEW PRODUCTS

After implementation of the Upgrading Project H.A.R. has the possibility to produce new oil products according to the stringer environmental regulations, i.e. :

- Unleaded gasoline (up to 50% of the total gasoline production, it is also possible to produce only unleaded gasoline by expanding isomerization unit to the Total Isomerization Process).
- MTBE to be used for gasoline RON enhancement **instead of lead** compounds.
- Diesel oil with a 0.3% wt sulphur.
- Fuel oil with a viscosity varying in a very narrow range.
- Increased LPG production, which can be utilized as automotive fuel in the greater Athens area.

8. COST OF ENVIRONMENTAL PROTECTION MEASURES

The cost of all envronmental protection measures is estimated to about 25% of the overall Upgrading Project investment cost. Such a high cost would have been prohibited for the project implementation unless pollution abatement measures could be coupled with production processes, such as :

- Sulpur compounds removal from fuel gas is combined with enhanced LPG production.
- FCC feedstock desulphurization is combined with an enhanced flexibility in changing the ratio of gasoline/diesel oil production.
- Installation of tertiary cyclones for FCC regenarator flue gases enables the installation of an expander.
- Treated waste water can be recycled reducing the fresh water demand.

Finally it should be noted that all environmental protection measures have been extensively reviewed by the greek environmental authorities and specialist called for this purpose (as for example Mr. P. Sutton from ERL) as well as by specialists of the European Investment Bank, since environmental protection was one of the key issues for project financing by the E.I.B., and approved. All these measures have been also presented in details to the local authorities of the adjacent to the refinery areas.

9. CONCLUSIONS

This presentation showed very briefly that H.A.R. Upgrading Project could be successfully coupled with sound pollution abatement measures. The experience of the subject project showed that it is possible new industrial projects to be realized in a way that operation of the industry will meet the stringest environmental regulations without the feasibility of the project to be adversally affected, provided that due consideration has been payed to the pollution during the early design stage, so that pollution abatement can be integrated with the production operations.

The operation of the new conversion units of H.A.R. started gradually almost one year ago. Environmentally bound process units were the first to be started in summer of 1987 and their performance is as expected.

10. REFERENCES

[1] Calvert, S., Englund, H.M., Handbook of Air Pollution Technology, John Wiley Interscience, N.Y., 1984.

[2] Notes on BPM for Crude Oil Refineries, 5/75, published as Appendix tc the Annual Report of HM Inspectorate of Pollution.

[3] TA-Luft (1985).

[4] ERL, Abatement of Air Pollution from Industrial Sources in the Greater Athens Area, April 1985.

[5] Huber L.J., Proc. 9th World Petroleum Congrece, 6 257 (1975).

[6] Grundsaetze fuer den Bau und Betrieb von Abwasserreinigungsanlagen in Erdoelraffinerien, ATV-VKS, A-701, 1984.

Table 1 : Comparison of H.A.R. effluents with similar refineries

Refinery	BP	ERLAG	ERN	ESSO	SHELL	H.A.R.
Capacity(t/d)	12,754	9,275	20,289	12,463	8,696	15,880
Waste Water flowrate(m^3/t)	0.245	0.09*/0,145	0.103*/0 243	0.160	0.190	0.113*/0.295

(*) Without cooling water system effluents contribution.

Table 2 : Comparison of waste water flowrate and pollution load from H.A.R. with other refineries

Parameter	Average (a) U.S.A. Refineries	Average (b) European Refineries	5 German (c) Refineries of Table 1	H.A.R.
Flowrate(m^3/t)	———	0.08-2.8	0.196	0.113/0.295
BOD_5 (kg/kt)	83	51	1.4	7
Phenols(kg/kt)	3	0.32	0.02	0.044
Hydrocarbons(kg/kt)	19	11	0.2	0.59

a) Source : API survey [6]
b) Source : [6]
c) Source : [6] , for these 5 refineries very string environmental regulation are applicable due to their location.

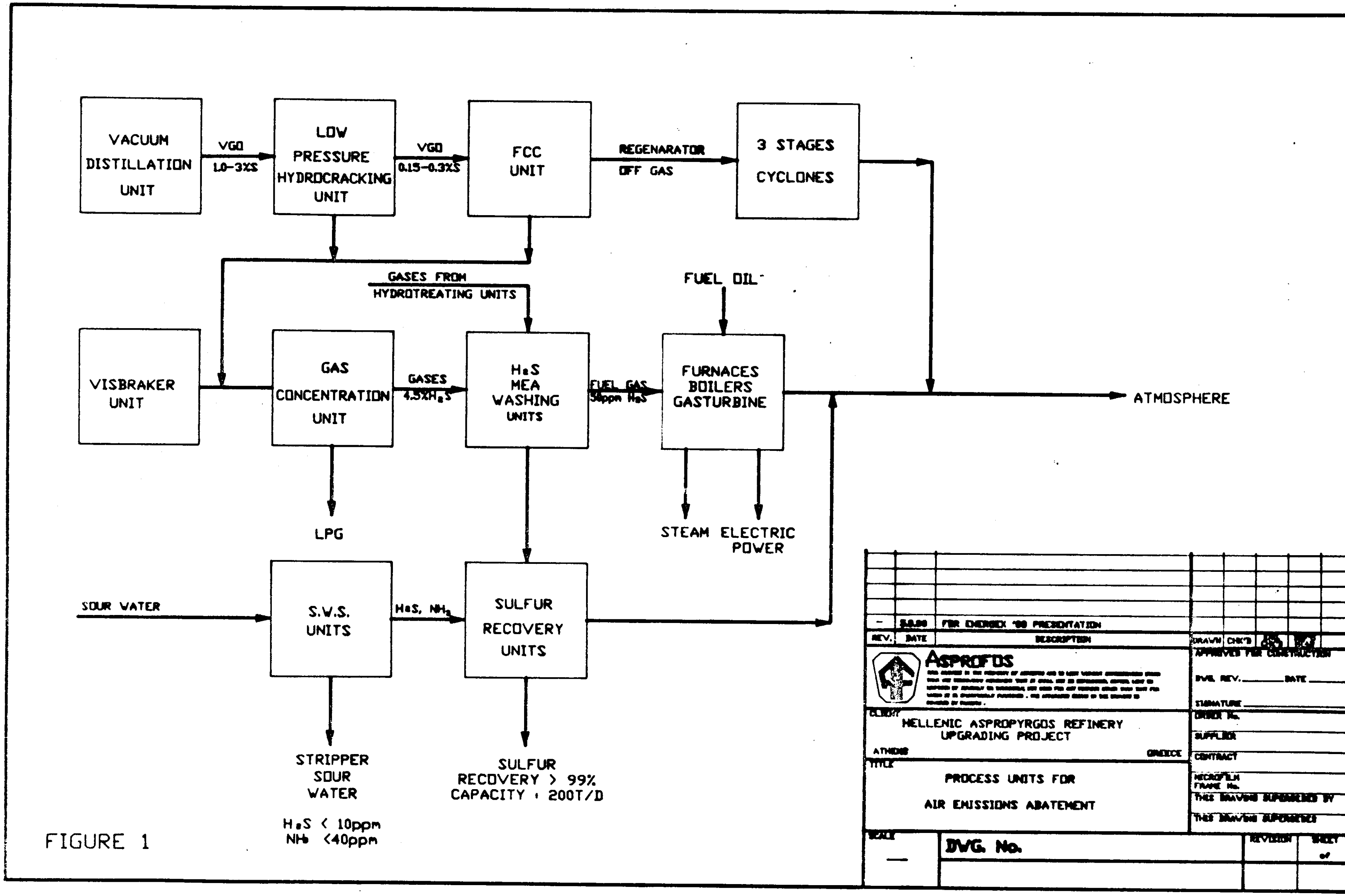

VACUUM DISTILLATION UNIT
VGO 1.0-3%S
LOW PRESSURE HYDROCRACKING UNIT
VGO 0.15-0.3%S
FCC UNIT
REGENARATOR OFF GAS
3 STAGES CYCLONES
GASES FROM HYDROTREATING UNITS
FUEL OIL
VISBRAKER UNIT
GAS CONCENTRATION UNIT
GASES 4.5%H2S
H2S MEA WASHING UNITS
FUEL GAS 50ppm H2S
FURNACES BOILERS GASTURBINE
ATMOSPHERE
LPG
STEAM
ELECTRIC POWER
SOUR WATER
S.W.S. UNITS
H2S, NH3
SULFUR RECOVERY UNITS
STRIPPER SOUR WATER
H2S < 10ppm
NH3 <40ppm
SULFUR RECOVERY > 99%
CAPACITY , 200T/D
REV.
DATE
DESCRIPTION
FOR ENERGEX '90 PRESENTATION
DRAWN
CHK'D
APPROVED FOR CONSTRUCTION
ASPROFOS
CLIENT
HELLENIC ASPROPYRGOS REFINERY
UPGRADING PROJECT
ATHENS
GREECE
TITLE
PROCESS UNITS FOR
AIR EMISSIONS ABATEMENT
SCALE
DWG. No.
REVISION
SHEET

FIGURE 1

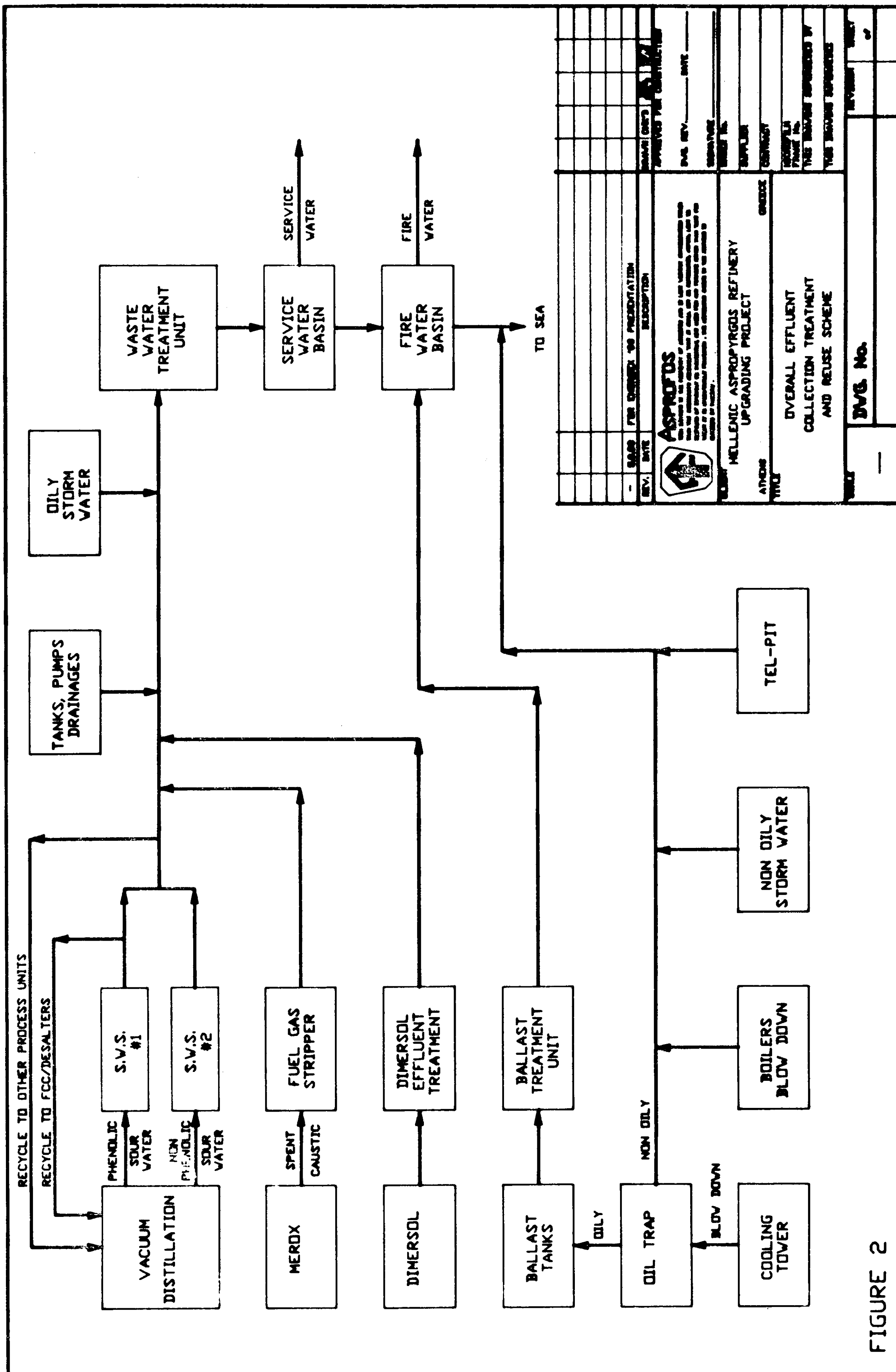

VACUUM DISTILLATION
PHENOLIC SOUR WATER
NON PHENOLIC SOUR WATER
S.V.S. #1
S.V.S. #2
RECYCLE TO OTHER PROCESS UNITS
RECYCLE TO FCC/DESALTERS
MEROX
SPENT CAUSTIC
FUEL GAS STRIPPER
DIMERSOL
DIMERSOL EFFLUENT TREATMENT
BALLAST TANKS
BALLAST TREATMENT UNIT
OILY
OIL TRAP
NON OILY
BLOW DOWN
COOLING TOWER
BOILERS BLOW DOWN
NON OILY STORM WATER
TEL-PIT
TANKS, PUMPS DRAINAGES
OILY STORM WATER
WASTE WATER TREATMENT UNIT
SERVICE WATER BASIN
SERVICE WATER
FIRE WATER BASIN
FIRE WATER
TO SEA
ASPROFOS
HELLENIC ASPROPYRGOS REFINERY UPGRADING PROJECT
ATHENS
GREECE
OVERALL EFFLUENT COLLECTION TREATMENT AND REUSE SCHEME
DWG. No.

FIGURE 2

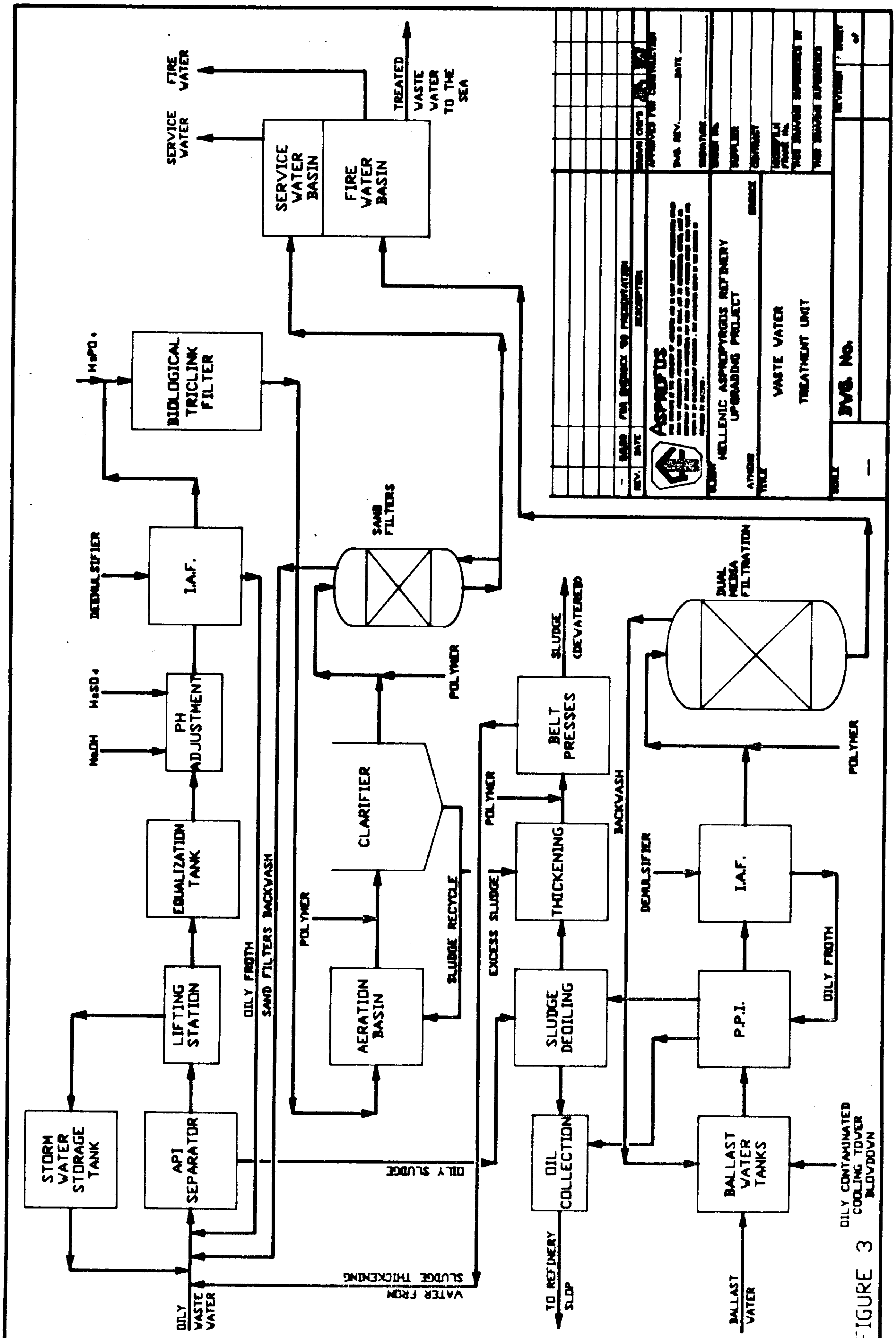

OILY WASTE WATER
STORM WATER STORAGE TANK
API SEPARATOR
LIFTING STATION
EQUALIZATION TANK
NaOH
H2SO4
PH ADJUSTMENT
DEEMULSIFIER
I.A.F.
BIOLOGICAL TRICLINK FILTER
OILY FROTH
SAND FILTERS BACKWASH
POLYMER
AERATION BASIN
CLARIFIER
SLUDGE RECYCLE
SAND FILTERS
SERVICE WATER BASIN
FIRE WATER BASIN
SERVICE WATER
FIRE WATER
TREATED WASTE WATER TO THE SEA
OILY SLUDGE
WATER FROM SLUDGE THICKENING
EXCESS SLUDGE
SLUDGE DEOILING
THICKENING
BELT PRESSES
SLUDGE (DEWATERED)
BACKWASH
OIL COLLECTION
TO REFINERY SLOP
BALLAST WATER
BALLAST WATER TANKS
OILY CONTAMINATED COOLING TOWER BLOWDOWN
P.P.I.
DEMULSIFIER
DUAL MEDIA FILTRATION
ASPROFOS
HELLENIC ASPROPYRGOS REFINERY UPGRADING PROJECT
ATHENS
GREECE
WASTE WATER
TREATMENT UNIT
DWG. No.

FIGURE 3

ENERGY CONSIDERATIONS FOR PRODUCTION OF COPPER BY HYDROMETALLURGICAL PROCESSES

M.A. EL-MARGHANI

DEPT. OF MATERIAL SCIENCES & ENGG.
EL-FATEH UNIVERSITY, TRIPOLI, LIBYA.

A B S T R A C T

Comparison of energy consumption for production of copper by the conventional electrowinning process and by newer process, the continuous hydrogen reduction process (CHR) is presented. Two alternative sources of hydrogen: reforming of natural gas and water electrolysis are considered in energy calculations. Energy analysis reveals that when source of hydrogen is by reforming natural gas the potential energy savings amount to producing 2.5 to 2.87 tons of copper by the CHR process per ton of copper produced by electrowinning. No energy saving is predicted when water electrolysis is source of hydrogen.

1. INTRODUCTION

Continuous hydrogen reduction of metal values from their salt solutions can compete favourably with conventional process of electrolysis (electrowinning) particularly if the cost of energy is a limiting factor. With abundance of low grade ores, a continuous hydrogen reduction process (CHR), shown in Figure 1, provides a better alternative to electrowinning since high throughputs can be processed at minimum operating costs. The objective of this work is to compare the energy consumption for the production of copper by electrowinning and by the continuous hydrogen reduction.

The energy requirements for the production of 100,000 tons of copper per year using the continuous hydrogen reduction process (CHR) are compared with literature values for three well-known processes employing at present the electrowinning step for the production of cathode copper. Since the CHR process requires hydrogen as a feed, two schemes of hydrogen production are examined[1]. The comparison between the CHR and electrowinning is made in energy units per ton of copper produced since specific cost figures are not available.

2. ENERGY ANALYSIS

2.1 Hydrogen Requirements

Sista[2] reported that an 80 percent yield to metallic copper could be achieved using the CHR process operating under the following conditions:

Reactor residence time	=	10 minutes
Total reactor pressure	=	3548 Kpa
Reactor average temperature	=	204°C
Inlet feed concentration	=	20 gr Cu^{++}/liter
Excess hydrogen input	=	25%

Based on an operating schedule of 360 days per year, the feed rate of copper leach solution can be calculated as

$$\frac{\frac{10^5 \text{ ton Cu}}{\text{yr}} \times \frac{2000 \text{ lb}}{\text{ton}}}{\frac{0.8 \text{ lb Cu}}{\text{lb } Cu^{++}} \times \frac{360 \text{ day}}{\text{yr}} \times \frac{63.54 \text{ lb } Cu^{++}}{\text{lb mole}} \times \frac{24 \text{ hr}}{\text{day}}} = \frac{455.5 \text{ lb mole } Cu^{++}}{\text{hr}}$$

For the reduction reaction

$$Cu^{-+} + H_2 \rightleftharpoons Cu + 2H^+ \qquad (1)$$

and using 25 percent excess hydrogen over the stoichometric rate, the hourly hydrogen feed rate is

$$\frac{455.4 \text{ lb mole } Cu^{++}}{\text{hr}} \times \frac{379 \text{ SCF-}H_2 \times 1.25}{\text{lb}_2\text{mole}} = \frac{215.7 \text{ MSCF}}{\text{hr}}$$

where (MSCF) denotes 1000 standard cubic feet at 60°F and 14.7 psia total

pressure. Therefore, the hydrogen requirement to produce one ton of copper in the CHR process would be

$$\frac{\frac{215.7 \text{ MSCF-H}_2}{\text{hr}} \times 360 \times 24}{\frac{100{,}000 \text{ ton Cu}}{\text{yr}}} = \frac{18.6 \text{ MSCF-H}_2}{\text{ton Cu}}$$

2.2 Energy Calculation

To supply the necessary amount of hydrogen for reducing copper in the CHR process, two alternatives are evaluated: catalytic reforming of natural gas and water electrolysis.

2.2.1 Hydrogen from natural gas

Steam reforming of natural gas is a widely used process for production of hydrogen whenever natural gas or paraffins are abundant and the overall reaction can be written as :

$$CH_4 + 2H_2O \xrightleftharpoons{\text{Catalyst}} CO_2 + 4H_2 \qquad (2)$$

Complete conversion of methane would produce four moles of hydrogen for every mole of methane fed. Typical requirements for such a process [3] are :

Natural gas per 1.0 MSCF-H_2 produced = 450 SCF

Power (for compression) per 1.0 MSCF-H_2 = 2.5 kw-hr

Therefore, the amount of natural gas required to produce 18.6 MSCF of hydrogen which in turn will produce one ton of copper in the CHR process is :

$$\frac{18.6 \text{ MSCF-H}_2}{\text{ton Cu}} \times \frac{450 \text{ SCF-CH}_4}{\text{MSCF-H}_2} = \frac{8.4 \text{ MSCF-CH}_4}{\text{ton Cu}}$$

and the electrical energy needed for compression in the gas reforming process would be :

$$\frac{18.6 \text{ MSCF-H}_2}{\text{ton Cu}} \times \frac{2.5 \text{ kw-hr}}{\text{MSCF-H}_2} = \frac{46.5 \text{ kw-hr}}{\text{ton Cu}}$$

Hence, and based on a 32.5 percent electric power generation efficiency, the total energy requirement to produce one ton copper in the CHR process which utilizes natural gas as the source of hydrogen is :

$$\frac{8.4 \text{ MSCF-CH}_4}{\text{ton Cu}} \times \frac{10^6 \text{ Btu}}{\text{MSCF-CH}_4} \times \frac{0.000293 \text{ kw-hr}}{\text{Btu}} \times 0.325 + \frac{46.5 \text{ kw-hr}}{\text{ton Cu}}$$

$$= 850 \text{ kw-hr per ton Cu}$$

2.2.2 Hydrogen from water electrolysis

Consider a reversible cell in which the overall reaction for water electrolysis is taking place under the standard state conditions of 25°C, 1 atm and all chemical species are at unit activity. Then the minimum value of electrical energy input in this cell must equal the change in Gibbs free energy of the reaction, i.e.

$$-W_{(\text{reversible work})} = \Delta G^{o} \tag{3}$$

But the change in Gibbs free energy is also proportional to the voltage applied across the cell in accordance with Faraday law given by

$$\Delta G^{o} = -nFE^{o} \tag{4}$$

where n is the number of Faradays (gram equivalents) passing through the cell to complete the reaction, F is Faraday's constant 23.06 Kcal per volt per gram equivalent (26.8 Ampere-hr per gram equivalent) and E^{o} is the cell standard potential in volts. At these standard conditions ΔG^{o} for the dissociation of water is 56.7 Kcal per mole of hydrogen, and from equations (3) and (4) the minimum electrical energy input and the cell voltage can be calculated as :

$$\frac{56.7\ \text{Kcal}}{\text{gr mole } H_2} \times \frac{454\ \text{gr mole}}{\text{lb mole}} \times \frac{1\ \text{lb mole}}{379\ \text{SCF-}H_2} \times \frac{1.17 \times 10^{-3}\ \text{kw-hr}}{\text{Kcal}} =$$

$$= 0.0795\ \text{kw-hr per SCF-}H_2$$

$$W = -79.5\ \text{kw-hr per MSCF-}H_2$$

$$E^{o} = -\frac{56.7\ \text{Kcal}}{\text{gr mole (2 equivalents per mole)}\ \dfrac{23.06\ \text{Kcal}}{\text{equivalent-volt}}}$$

$$= -1.23\ \text{volts.}$$

This is the theoretical dissociation potential for water. In practice higher potentials, around 2 volts, are required in order to overcome irreversible resistance (overvoltage) on the electrodes. With a cell voltage of 2.0, the amount of electrical energy needed for the generation of 1000 SCF of hydrogen would be :

$$W = -4 \times 23.06\ \frac{454}{379} \times 1.17 = -129.3\ \text{kw-hr/MSCF-}H_2$$

Define an electrolysis cell efficiency as :

$$= \frac{\text{Heating value of } H_2 \text{ output}}{\text{Electrical energy input}} \tag{5}$$

Thus, by taking a 32.5 percent conversion of heat into electrical energy (0.0105 MM Btu per kw-hr) and 325 Btu per SCF-H_2 as the heating value of hydrogen, the efficiency for a 2-volts cell producing 1000 SCF-H_2 would be:

$$= \frac{1.0 \text{ MSCF-}H_2 \times 0.325 \text{ MM Btu per MSCF-}H_2}{129.3 \text{ kw-hr per MSCF-}H_2 \times \frac{0.0105 \text{ MM Btu}}{\text{kw-hr}}} = 0.24$$

as compared to the 70 percent efficiency for gas reforming. This large difference in efficiencies results from the need to supply "high availablity" electrical energy. Therefore, to supply the CHR process with hydrogen produced by water electrolysis.

$$\frac{18.6 \text{ MSCF-}H_2}{\text{ton Cu}} \times \frac{130 \text{ kw-hr}}{\text{MSCF-}H_2} = 2430 \text{ kw-hr per ton Cu}$$

of electrical energy would be needed as compared to about 850 kw-hr per ton copper needed when hydrogen gas is produced in a gas reformer.

COMPARISON AND CONCLUDING REMARKS

In a recent publication [4] several hydrometallurgical processes involving electrowinning to produce cathode copper have been evaluated. The evaluation involves an assessment of the material and energy requirements as compared to the equivalent pyrometallurgical processes with a capacity of 100,000 tons of copper per year. The energy requirements for each process were assessed in two respects : (1) an operational requirement such as electrical energy and steam generation, and (2) the energy requirement associated with various chemicals consumed or produced in the processing steps. The most energy intensive step, however, has been found to be the electrowinning. It consumes between 30 to 70 percent of the total energy requirement as shown in Table 1.

While making comparison, however, it is assumed that the energy consumed in all front-end operations of mining, grinding, concentrating, leaching and separating would be the same in the CHR process as well as the counterpart processes listed in Table 1. Furthermore, the potential energy savings by using the CHR process supplied with required hydrogen gas produced by either water electrolysis or natural gas reforming over each of these processes is expressed as :

$$\frac{\text{amount of electrical energy required to produce one ton of cathode copper}}{\text{amount of electrical energy required to produce one ton of copper by the CHR process}}$$

as shown in the last column of Table 1.

Using the first approach, and since the CHR process requires 2430 kw-hr for every ton of copper produced when a water electrolyzer is incorporated with it as a hydrogen supplier, the potential energy savings range from 0.8 to 1.0 ton of copper produced by CHR process per ton of copper produced by electrowinning. Thus, calculations reveal no potential in energy savings by suing the CHR process with water electrolyzers as source of hydrogen over the existing electrowinning step. However, the reverse is -

the case when reformed natural gas is the source of hydrogen in the CHR process, resulting in potential energy savings; 2.7, 2.5 and 2.87 ton of copper produced by CHR per ton of cathode copper as shown in Table 1. These potential energy savings represent at least a two-fold increase in the production capacity by using the CHR process.

4. REFERENCES

[1] El Marghani, M.A. Ph.D. Thesis, Univ. of Oklahoma, U.S.A. (1983).

[2] Sista, K.M. Ph.D. Thesis, Univ. of Oklahoma, U.S.A. (1978).

[3] James, G.R. Chemical Engineering, (Dec.1961), 161 - 166.

[4] U.S. Department of Energy Report, DOE/CS/40132,2 (1980).

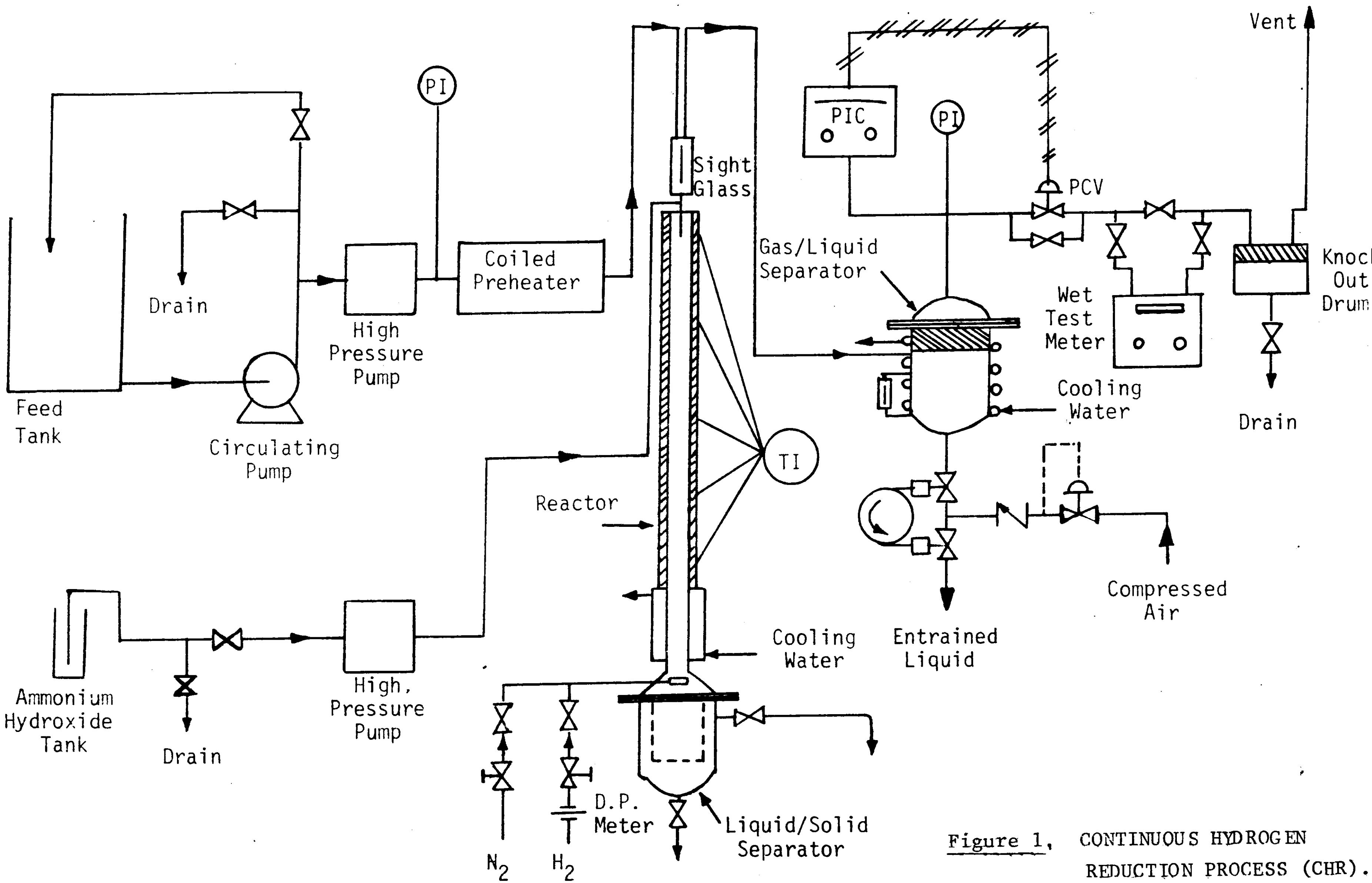


Figure 1, CONTINUOUS HYDROGEN REDUCTION PROCESS (CHR).

TABLE 1

ENERGY REQUIREMENTS FOR COPPER ELECTROWINNING PROCESS [4] AND CALCULATED POTENTIAL ENERGY SAVINGS BY USING THE CONTINUOUS HYDROGEN REDUCTION PROCESS AS A SUBSTITUTE FOR ELECTROWINNING OF COPPER

Process Name	Total Energy Requirement $\frac{\text{kw-hr}}{\text{ton Cathode Cu}}$	Energy Consumed in Electrowinning $\frac{\text{kw-hr}}{\text{ton Cu}}$	% of Total Energy consumed in Electrowinning of Copper	Potential Energy Savings (ton Cu produced by CHR process per ton cathode Copper)	
				Hydrogen by Water Electrolysis	Hydrogen by Natural Gas Reforming
Nitric-Sulfuric Acid Leach	7090	2300	32.4	$\frac{2300}{2430} = 0.95$	$\frac{2300}{850} = 2.7$
Roast-Leach Electro-winning	2900	2134	73.58	0.87	2.5
Ferric Sulfate-Acid Leach	4710	2445	51.9	1.0	2.87

SOUR CRUDE / GAS PRODUCTION AND PROCESS INSTALLATIONS, A CLASSIFICATION SOCIETY'S CONTRIBUTIONS TO THEIR SAFE AND CONTINUOUS OPERABILITY

ERWIN MUNSKE

GERMANISCHER LLOYD HEAD OFFICE, P.O. Box 11 16 06,
D - 2000 HAMBURG 11
Phone: (0)40 361490 FAX: (0)40 36149200 Telex: 212828 GLHHD

ABSTRACT

Involvement of an independent society for the assessment and approval of the design and fabrication/installation of plants for the production/ processing of hydrocarbons and, in particular, sour oil/gas installations, is increasingly governed by

- statutory requirements
- owners'/operators' economical considerations.

Desirability of independent party involvement at a stage as early as the planning phase is obvious. The extent of this involvement may vary from case to case. The scope of work performed by Germanischer Lloyd on previous projects has been, e.g.

- design approval, inspection and certification of installations under plant/personnel/environmental safety aspects, classification and performance of periodical inspections by the classification society, issuance of a certificate of fitness. This provides a basis for granting the operating licence by governmental or other official agencies.

1. INTRODUCTION

Germanischer Lloyd, being one of the leading international classification societies, was established in 1867. The society's prime concern from the beginning was the safety of merchant shipping. Like today, after plan approval a ship was inspected regularly during its building period by engineers from the classification society. After successful completion of the sea trials the society issued a certificate which served the insurance companies as a basis for underwriting and premium fixing.

Because of the international character of the marine business the establishment of branch offices and agents world wide became a necessity in order to effectively serve the shipping industry.

When shipping and, in particular, ship safety became a government concern (i.e. in the second half of the 19th century) the practical task

of approving the design and construction of ships on government behalf was delegated by governments to those people who were competent in this field - the classification societies. Germanischer Lloyd has thus been authorized by the governments of about a hundred shipping nations to act on their behalf for the benefit of ship safety.

Backed by their marine expertise and considerable general industry experience Germanischer Lloyd (GL) consequently expanded into the safety and quality sector of the oil and gas industry on land and offshore.

2. CERTIFICATION SERVICES BY GERMANISCHER LLOYD

The society has been involved so far in a range of projects of varying magnitude. Some examples are shown on the photos.

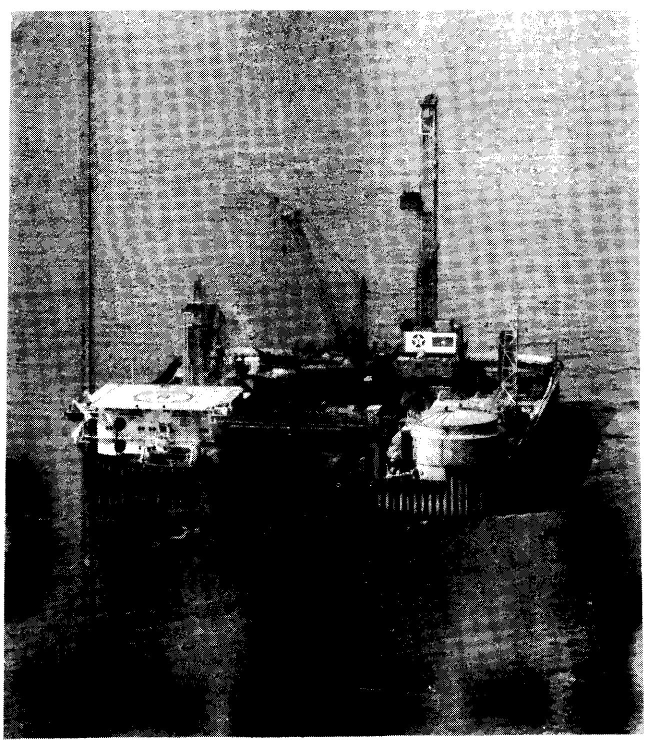


Fig. 1
Drilling & production platform Mittelplate-A, on artificial island offshore North Germany, in tidal North Sea waters

The handling of a complete project generally includes the classification of the installations and issuance of a certificate of fitness for them. The certificate is valid for five years and will be renewed on the condition of periodical inspections being performed by GL. This means that GL acts in the capacity of a certifying body on the basis of its classification rules and of agreed standards and project related specifications.

Activities by GL start with the assessment and approval of the design of plant and installations onshore/offshore. Depending upon their location a hazard and operability study (HAZOP) may be required. Earthquake analyses and environmental studies (waves, currents, wind, soil characteristics, traffic) are part of the design appraisal. Area classification (hazardous/ non-hazardous) is another important item.

Of vital significance is the subject of materials with regard to the highly corrosive wet hydrogen sulfide (H_2S) increasingly occurring in oil and gas produced. Due to the generally known chemical reactions between

steel and H_2S piping and pressure vessels are endangered by hydrogen induced cracking (HIC) and sulfide stress corrosion cracking (SSCC). The latter can be controlled largely by using steels of low or moderate strength plus low operating stress levels. HIC, however, has been observed on all grades of carbon steels even in cases where no external stresses existed. HIC is caused by diffusion of hydrogen into voids in the steel which occur in particular at the interfaces of metal and impurities. As hydrogen in these voids combines into H_2 a pressure develops which increases as more H_2 atoms are formed. Final component failure due to blistering or cracking is the result.

Factors which help to keep control of the problem are

- use of specially treated steels with low content of impurities and limited hardness
- reducing the operating stress level, increase of corrosion allowance
- avoiding of internal stresses in welds by applying post weld heat treatment (PWHT)
- proper oil and gas treatment for dehydration
- periodical inspection of the component in service by NDT.

It is obvious that a closely knitted system of carefully documented inspections is indispensable which range from the materials at the mill through fabrication (welding) and installation (free of externally imposed stresses)

Out of the total range of project components a few more important ones are given here in order to explain the general approval philosophy:

2.1 Fixed Offshore Platforms

(i) Design approval

Documents to be reviewed or approved by GL:

- Building specifications incl. data and assumptions on environmental conditions (waves, currents, wind, soil, earth-quake)
- Material specifications
- Strength calculations of main structures incl. piles, jacket, deck structure and the connections between piles/jacket/deck, helideck, main attachments to jacket (e.g. barge bumpers, boat landing), dolphins
- Fabrication drawings for jacket, decks, dolphins, weld connections, piles, helideck, foundations for equipment, attachments to the structure.

(ii) Fabrication surveillance

Activities to be performed before and during fabrication:

- Assurance of qualification of fabrication yard
- Welder's qualification
- Approval of welding procedures and qualification tests, check of welding sequence plans
- Inspection of materials at source
- Surveillance of fabrication, evaluation of NDT results
- Final inspection incl. dimensional checks

(iii) Installation surveillance

Activities before and during installation:

- Examination of procedures and calculations for loadout, seafastening, transportation, installation (incl. piling, grouting, levelling)
- Surveillance of loadout, seafastening, installation (incl. piling, grouting, levelling and all weldings).

2.2 Subsea Pipelines

(i) Design approval

Documents to be reviewed or approved by GL:

- Building specifications incl. design parameters, minimum bending radii etc.
- Material specifications
- Routing of the pipelines (sea bottom configuration, landfalls, anchor blocks for shore approach, proximity to shipping lanes, crossing of other pipelines or cables)
- Strength calculations with respect to internal and external stresses/ loads (pipeline, risers, valves)
- Pipeline plans and sections incl. location and type of valves and isolating flanges, riser protection in splash zone
- Corrosion protection (distribution of anodes, coating)
- Pipeline on-bottom-stability (weight coating design)
- Procedures for pipe laying, abandon and recovery, tie-in, riser installation (incl. tensioner control, installation stresses, stinger/roller adjustments, stresses during laying)
- Trenching and burial procedures, appraisal of burying equipment
- Cleaning, pressure test and drying procedures.

(ii) Fabrication surveillance

GL activities before and during pipe fabrication:

- Assurance of qualification of pipe manufacturer
- Inspection of pipe materials at source
- Surveillance of pipe fabrication and coating (corrosion/weight)
- Evaluation of destructive/non-destructive tests.

(iii) Installation surveillance

GL activities before and during installation:

- inspection of laybarge for suitability (general condition, stinger with controls, nautical equipment, helicopter facilities, technical and personnel safety, pipe handling equipment, welding equipment/consumables, tensioner station, winches, wires and chains, anchors)
- identification of pipes and/or prefabricated spools
- checking of pipe and conditions (end bevel, cleanness, corrosion/ weight coating)
- welder/procedure qualification where necessary
- inspection of welding and final coating
- evaluation of NDT
- supervision of actual pipe laying, evaluation of divers' reports, route check
- final inspection which includes internal cleaning of the line, approval of equipment for pressure test, supervision of test, depressuring, inhibiting/drying of the pipeline.

An impressive example of a more sophisticated type of pipeline laid in the Baltic Sea is shown in figures no. 2 and 3. Because of a nearby beach, crowded in summer, extraordinary measures for leak prevention were required by the authorities.

2.3 Onshore Pipelines

These pipelines are treated in analogy to those offshore.

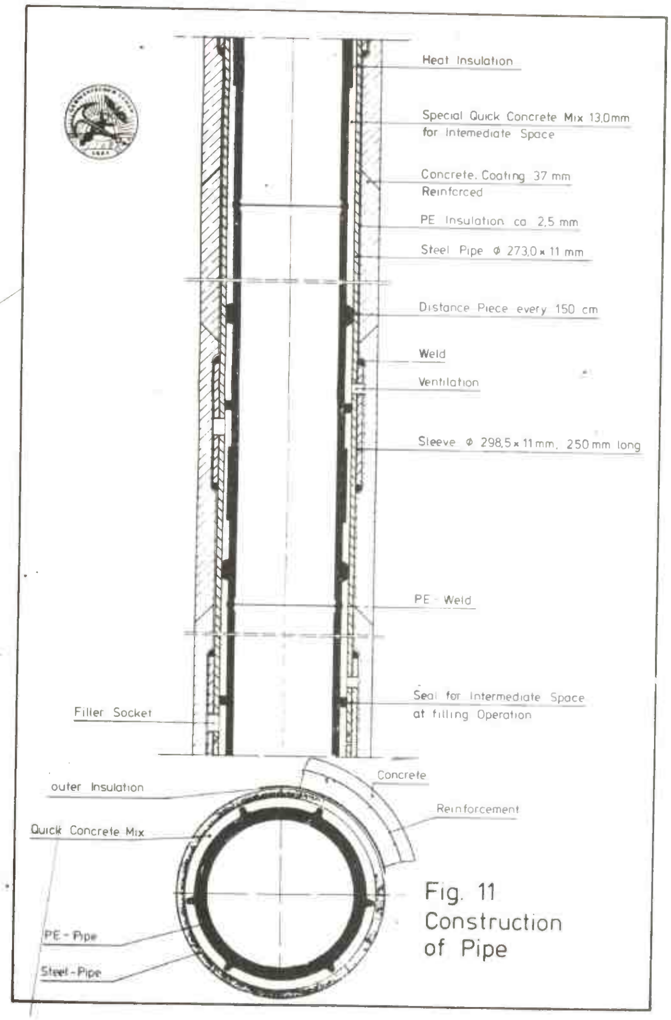


Fig. 2

Section through a double wall subsea pipeline in the Baltic Sea. Because the pipeline had to be routed through a recreation area (offshore and beach) this design was chosen to satisfy the authorities.

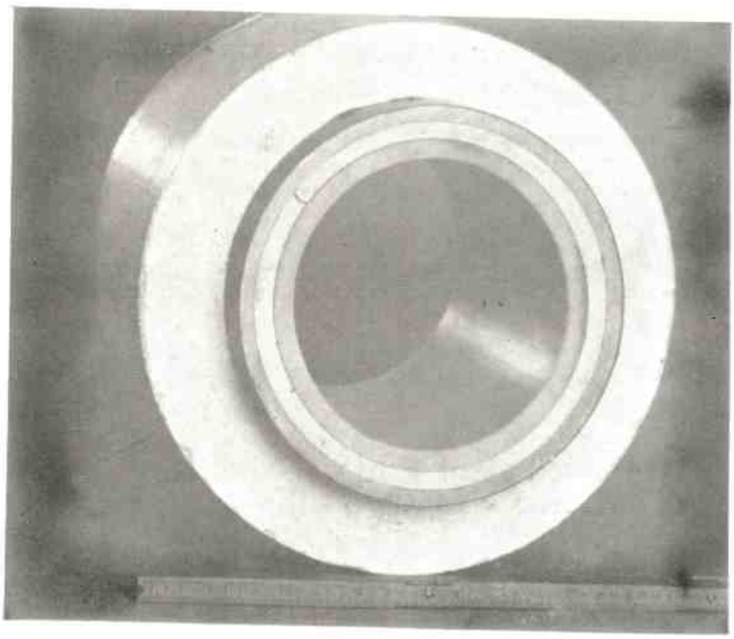


Fig. 3

Section through the completed pipeline

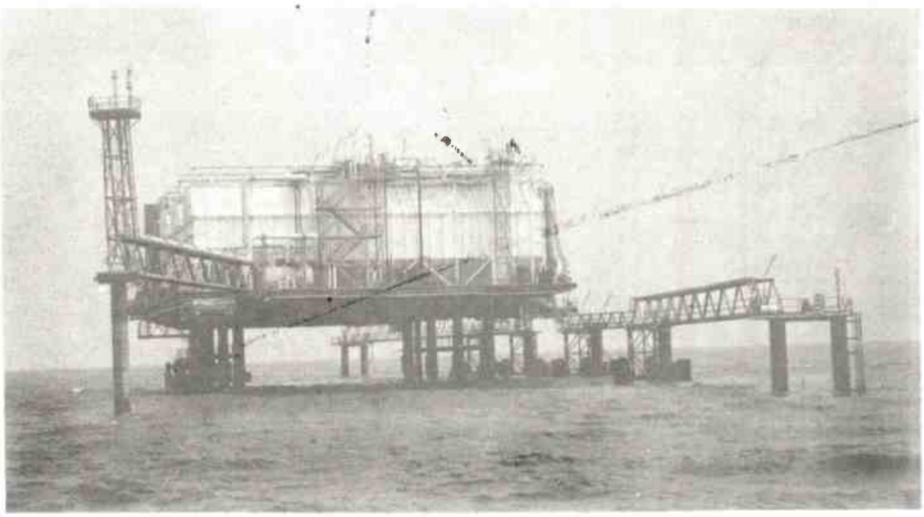


Fig 4 Ethylene Offshore Terminal (Egypt)
A "world first", certification and classification by GL

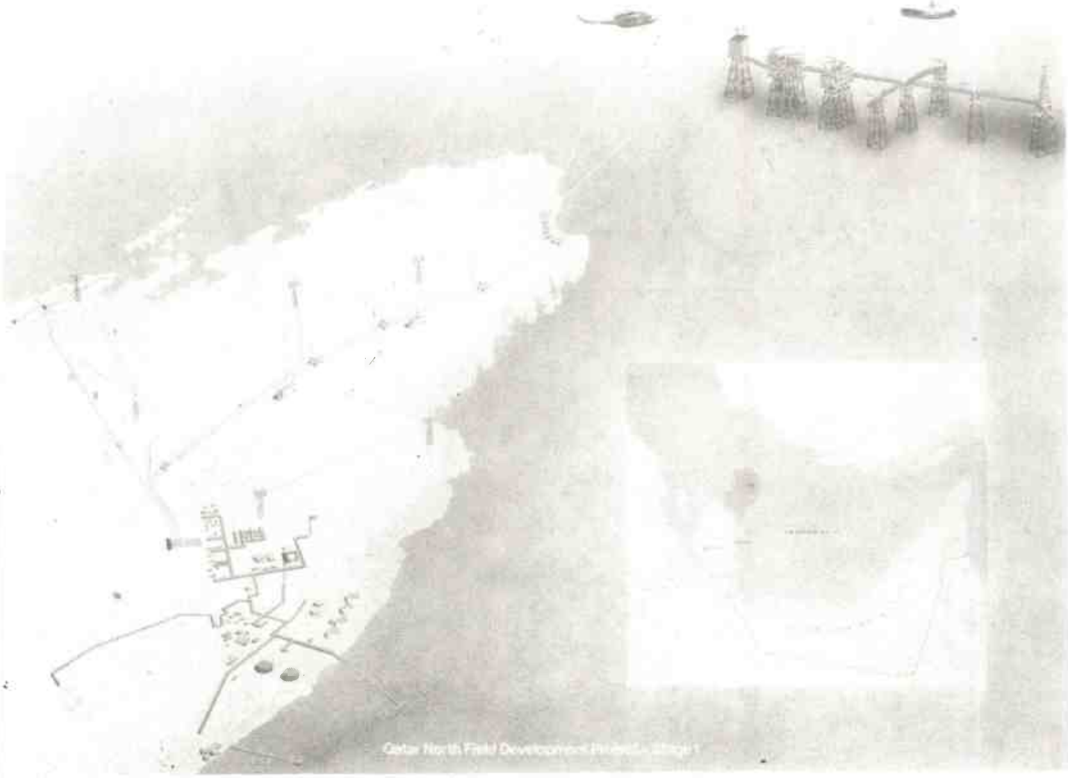


Fig. 5 Qatar North Field Development Project - one of the more recent challenges to GL

2.4 Other Plant Components

The other components of an installation or plant are treated in the same manner. This applies, e.g., to

- Storage tanks
- Boilers
- Fire protection/fighting
- Gas detection and safety systems
- Control systems
- Life saving appliances and emergency evacuation systems.
- Machinery (pumps, compressors)
- Cranes and winches
- Electrical equipment
- BOP and ESD systems

2.5 Periodical inspections

While a plant/installation may be designed and certified in accordance with the latest state of the art its continued and safe operation can be achieved only by monitoring its performance. An effective tool therefor is a system of periodical inspections by the owners/operators and the classification society.

Each plant section is analysed in respect of failure probability and the consequences of breakdowns on the overall plant availability. While GL's prime concern is the safety of plant and personnel, its scope of inspection may be increased by agreement with the operators. GL, in close liaison with the operators develops check lists and test programs for each plant area and down to essential components. Thereby failure rates and trends of wear and tear can be assessed.

Fig. 6
Blast cleaned node of underwater structure ready for periodical inspection

Periodical inspection virtually starts from the bottom upwards, i.e. the structure is one of the areas to be checked. Unless required by unusual events (earthquake, collission) the normal inspection would annually cover 20 % of the underwater structure so that in the course of five years a complete structural inspection has been made. On structural drawings the sections of particular interest (e.g. high local stresses) are marked and then checked locally. Each annual inspection report then contains a set of

drawings, a video tape and a collection of still photos. Thus the condition of anodes, structural members, marine growth and sea bed are monitored.

Particular attention must be paid to materials exposed to H_2S and NDT is therefore an obligatory part of the inspections.

Another area of concern are such safety items which under normal operating conditions are not used. This applies, e.g., to emergency shutdown (ESD) systems which, after an initial "running-in" period of the plant, may not be needed for months.

Until recent years difficulties have been experienced with detectors for combustible gas in an atmosphere containing also traces of H_2S. This H_2S contaminated the active surface of the detecting element thus reducing its effectiveness to zero without giving any warning. Operators were thereby kept in a false state of safety. Before the development of more reliable detectors the problem was overcome by increasing the frequency of recalibration.

It is needless to say that an efficient and meaningful inspection system the costs of which are to justify its application must be based on sufficiently detailed documentation reflecting

- the building and start-up period of the plant and components and
- each subsequent inspection.

This enables the management to monitor and evaluate the plant performance and at the same time assures the classification society of the safe condition of the plant or installation.

3. CONSULTING

With the experience gained in the course of the activities outlined in sections 1 and 2 it was only a logical consequence for GL to move into consulting. In this respect the Society successfully completed a wide range of interesting tasks like

- Feasibility study for underwater storage of oil
- Safety studies for production and process plants onshore/offshore
- Hydrodynamic investigations
- Development of computer programs for barge transport and installation of heavy lift modules
- Vibration analyses for structures and machinery
- Damage assessments, recommendations and procedures for remedial measures
- Warranty surveyors for load out and sea transport of modules
- Contingency plans for emergencies
- Procurement of pre-commissioning engineers
- Training programs for clients' personnel
- Design appraisals for wind energy converters, performance monitoring and evaluation.
- Quality assurance systems, development, auditing of companies

Naturally, consulting covers also the Society's traditional field of shipbuilding. In this area a large number of studies are made the results of which contribute to the technological progress in shipbuilding.

4. GEOGRAPHICAL FEATURES

GL has been and still is engaged in oil/gas or petrochemicals related projects in areas as

- North Sea, Baltic Sea
- People's Republic of Libya
- Aegean Sea
- Greece
- Mediterranean Sea
- Egypt
- Red Sea
- Arabian Gulf

Each project offers its individual challenges to which GL adequately responds by providing an engineering team especially tailored for the job. This applies also to the latest large project, the Qatar North Field Development. The Qatar General Petroleum Corporation awarded the contract for third party certification to GL (see fig. no. 5).

5. ADVISORY SERVICES TO GOVERNMENTS

GL has been and is advising governments and international agencies, either directly or by assigning experts to delegations or working groups on marine safety, offshore installations, innovative technologies:

- Federal Republic of Germany, Ministry of Transport
Ministry of Research & Technology
Federal Mining Authorities
- United Kingdom, Department of Energy
Department of Transport
- Norway, Petroleum Directorate
- International Maritime Organisation (IMO)
- International Association of Classification Societies (IACS)

GL thereby actively participates in and keeps abreast of international technological developments in the Society's domains.

6. CONCLUSION

It follows from the foregoing that the timely engagement of the services of Germanischer Lloyd as a third party certifying body in an oil or gas related project will help to

- avoid errors in planning and designing
- improve fabrication and installation
- facilitate final testing and start up
- ensure continued productivity and safety for plant and personnel through periodical inspections
- economize on the overall project

for the benefit of the owners and the industry in general.

Acknowledgements:

Photo nos. 1 - 3: Deutsche Texaco, Hamburg
no. 4: Egyptian General Petrochemical Company, Alexandria
no. 5: Qatar General Petroleum Corporation, Doha
no. 6: North Aegean Petroleum Comp. E.P.E., Athens

INDOOR RADON
- AN OVERVIEW OF A SERIOUS INDOOR AIR QUALITY PROBLEM

Gren Yuill, Ph.D.
G. K. Yuill and Associates Ltd.
Winnipeg, Canada

ABSTRACT

This paper describes the indoor air pollution problem caused by radon. It is intended as an introduction to the problem for those who have not yet had to deal with it. The first part of the paper is a review of the background to the problem. It describes the physics of radon and its progeny, the health risk of radon exposure and the evidence which made it known, the overall exposure of the population, and how radon gets into houses. The second part of the paper describes some of the techniques which have been used to solve the problem.

1. THE PHYSICS OF RADON

1.1 Radon As Part of the Uranium-238 Decay Chain

Uranium-238 is a radioactive isotope which is relatively common in the earth's mineral materials. Its concentration varies widely, but there are detectable traces in most rocks and soils. Uranium-238 has a half-life of 4.47 billion years, so its concentration in the earth's crust is constant.

Uranium-238 decays through a chain of four daughter products to produce radium-226, with a half-life of 1,600 years. This chain of decay is shown in Fig. 1. All the chemical substances in this chain are chemically active solids, so they tend to remain in the location where they are produced. When radium-226 decays, this changes. The daughter product produced is radon-222, which is a noble gas. A noble gas is a gas which is chemically stable and does not react with other chemical substances. This means that the radioactive atoms of radon-222 released in the soil are not bound there. They move into the air in the pores between the soil particles. They can then move with the soil air, or diffuse through it, to some new location. Since radon-222 has a half-life of 3.8 days, it can move quite far before decaying and may leak from the soil into the atmosphere or into the air in a house. In the atmosphere, radon-222 continues to decay and never builds up to a dangerous level. In a house, soil air with a high radon-222 concentration can become trapped and can be hazardous to the occupants.

1.2 Radon-222 and Its Daughter Products

When radon-222 decays, it produces polonium-218, which is also radioactive. A chain of radioactive isotopes of lead, bismuth and polonium follow, until eventually lead-206, which is a stable (non-radioactive) isotope, is produced. This decay chain is shown in Fig. 2.

Because radon-222 is a noble gas, it diffuses throughout the air in a room. A person in the room will breathe it in and out along with the air. When it decays, it gives off an alpha-particle, which will move only 4 cm in air, and can be stopped by clothing, or even skin. Thus most of the radon-222 decays which occur in a room are harmless to us. Only when radon-222 happens to decay when it is in our lungs can it do any harm. This is because the tissue lining the lung is particularly sensitive. However, it would take a very high concentration of radon-222 in the air to result in a significant amount of damage to our lungs.

The real hazard caused by radon-222 results from the decay of the daughter products which it produces. As can be seen from Fig. 2, the first four daughters all have half-lives of less than one-half

hour. These daughters are all chemically active. This means that when they are produced in the air of a house by the decay of radon-222 which has leaked into it, they tend to cling to dust particles in the air or to solid surfaces which they may contact. These daughter products can be carried to the surface of the lung tissue by the dust particles they are bound to, or they may bind to the lung tissue directly.

The lungs have a mechanism for removal of particles which lodge in them, but it is not fast enough to clear the radon daughters before they decay. The two most harmful decays are those of Polonium-218 and Polonium-214, which produce alpha-particles. These particles have a short range but they are released close enough to the sensitive tissues of the lungs to reach them. Alpha particles do a great deal of damage to tissues which they do strike. It has been found that this tissue damage in the lungs can lead to lung cancer.

Of course, not all radon daughters end up in the lungs. Most of them bind to other surfaces, either directly or on dust particles, and decay harmlessly there. If this were not true, and all the Polonium-218 and Polonium-214 atoms remained in the air, they would be said to be in equilibrium with the radon-222 in the air, and for every radon-222 decay, there would be two alpha-particles emitted by the decays of the two polonium isotopes. The equilibrium factor in this case would be 1. Equilibrium factors less than 1 account for the fact that some of the polonium atoms are removed from the air before they can decay. For example, if half the atoms of polonium-218 and polonium-214 produced as a result of the decay of radon-222 were removed from the air before they decayed, the equilibrium factor would be 0.5. Equilibrium factors tend to be in the range from 0.2 to 0.6 in houses.

2. HEALTH RISK DUE TO RADON

2.1 The Evidence for the Health Risk

The reason for the concern about radon in houses is that the radioactive decay of the radon daughters in the lungs causes lung cancer. The primary evidence for this is the increased incidence of lung cancer among mine workers who have been exposed to higher-than-average levels of radon. However, this evidence is also supported by animal studies and by detailed studies of lung function and the way in which radon daughters are deposited there. In fact, the health risk due to radon is relatively well understood, perhaps better than that due to any other environmental pollutant.

Most researchers believe that the risk of lung cancer due to radon in mines can be applied directly to determining the risk due to exposure in houses. The risk of lung cancer is believed to be proportional to the accumulated exposure to radon daughters. This means that a very high exposure for a short period of time is no more dangerous than a much lower exposure for a proportionally longer period of time. It also means that there is no safe level of radon. Reducing your radon exposure by 90% will reduce your probability of getting lung cancer from radon exposure by 90%, but there is no threshold at which your risk drops to zero.

2.2 The Exposure of the Population

Only a small fraction of homes have had their radon levels measured, so there is still some uncertainty about the range of radon concentrations. One of the best reviews of this topic was done by Lawrence Berkeley Laboratory, who studied the results of 38 radon measurement projects. Their results are shown in Fig. 3. This figure shows the percentage of U.S. houses which are in each range of radon concentrations. It is likely that the distribution would be reasonably similar in other cold to temperate climates.

When this population exposure is combined with the estimate of risk based on the miner studies discussed in the previous section, the overall risk to the population can be estimated. The result is that from 10% to 15% of all lung cancers are caused by radon exposure. This means that about 1,200 to 1,800 Canadians are dying annually of lung cancer caused by radon exposure, with similar death rates in other countries.

2.3 Comparison With Other Radiation Exposures

In the early 1980's it was believed that indoor radon supplied about 40% of the radiation dose of the population of the industrialized countries. As more measurements have been taken, it has become apparent that our radiation dose from radon is much higher than that. Recent studies have estimated that the figure is over 60%. A Swedish analysis divided up our radiation dose as follows.

Indoor radon	67%
Other natural radiation	21%
Medical and dental	12%
Nuclear weapon fallout	0.20%
Nuclear energy	0.03%

Radiation from other sources such as fire alarms, microwave ovens, and TV screens are completely negligible by comparison.

These figures will be surprising to most people, who get their ideas about radiation hazards from the news media. Reactor emissions may be more newsworthy, but houses are a far greater source of radiation. "But what about Chernobyl and

Three Mile Island," some may object. The fact is that even these accidents were small in scale compared to the radon problem. The overall exposure of the European population to radiation from Chernobyl in the year following the accident was only 16% of the same population's exposure to radiation from radon during the same year. This figure includes the residents of Chernobyl itself. In Finland, which got one of the higher radiation doses from Chernobyl, the dose was only 1% of that due to radon in the same year.

Three Mile Island was an economic disaster for the Utility which owned the reactor, but it was not significant as a source of radiation. It is unlikely that any householder in the vicinity of the reactor got as high a radiation dose from it on the day of the accident as he got from radon in his own house the same day.

These comparisons have been made between the average radon level in houses and the radiation levels from other sources. Most houses in which radon mitigation projects are carried out will have much higher radon levels. There are probably 100,000 Canadian houses with radon levels at least six times the national average. In fact, there are many houses which expose their occupants to more radiation than is allowed for workers in a uranium mine or a nuclear power plant.

This comparison of radiation exposures from various sources is significant because the radiation exposure of the population can be estimated more accurately than the death rate due to that exposure. Thus we can be more certain of the relative risk due to radon, compared to that due to medical and dental exposure, for example, than we can be of the absolute risk of either one.

2.4 Comparison With Other Health Risks

Another way of putting the hazard of radon into perspective is to compare it with other health risks, including other air pollutants as well as other causes of death such as accidents. The risk level of radon is far higher than that of any other air pollutant. Most pollutants are regulated at lifetime risk levels of one in 100,000 to one in a million. This risk of radon in the average house is a thousand times higher. In fact, the risk of all other air pollutants combined is probably less than the risk of radon.

The reason for the attention of governments to other far less dangerous pollutants is not hard to determine. Radon can't be regulated because it isn't anyone's fault. It's a natural phenomenon. To regulate it would require regulation of every household. Governments may set guidelines for radon control, but it will be up to individual homeowners to decide whether or not to follow these guidelines.

Another way of assessing the hazard of radon is to compare it with other risks we face. This kind of comparison has been carried out in the United States by the U.S. Department of Health. A person living in a house with the average level of radon (1.3 picoCuries/L) has the same risk of dying from radon-induced lung cancer as he has from drowning. At 4 picoCuries/L, the U.S. Government's recommended action level, his risk is the same as that of a person who works twenty years as an auto racer or tightrope walker, and is greater than his risk of being murdered or of committing suicide. At 20 picoCuries/L, the Canadian Government's recommended action level, his risk is about twice as high as that of dying in a traffic accident.

These comparisons emphasize that radon is a significant risk to our lives. To keep this risk in perspective, smoking causes 7 to 10 times as many lung cancer deaths as radon. Smoking a package of cigarettes per day causes the same risk of lung cancer as about 13 picoCuries/L of radon in a house.

Relating the risk of death due to radon to that of these other causes emphasizes the fact that radon is a significant hazard. However, there is one major difference between radon and these other hazards. To avoid some of these other hazards is impossible, while others may require a change of lifestyle we are reluctant to make, or the breaking of a habit which is very difficult to break. Radon, on the other hand, is easy to avoid. As will be seen later in this paper, it is possible to sharply reduce the levels of radon in houses at relatively low cost.

3. SOURCES OF RADON IN HOUSES

3.1 Introduction

The major sources of radon in houses are:

1. soil air flowing into the house through underground openings, and carrying in radon produced by the decay of radium in the soil,
2. radon carried into the house dissolved in well water and released into the air when the water is used, and
3. radon released directly into the house by building materials which are high in radium.

Three other sources which have sometimes been encountered are collections of minerals which contain radium-bearing rocks, rock-filled heat storage systems in solar heated houses, and the burning of radon-bearing natural gas or propane in unvented appliances.

3.2 Radon in Soil Air

By far the most significant source of radon in houses is the infiltration of radon-laden soil air. (See Fig. 4) This has only been realized in the past few years.

The first study of radon in residences was in Swedish houses which used alum shale with a very high radium content as the aggregate in the concrete. This led researchers to suspect building materials when radon was found in houses elsewhere. For the next few years, most radon measurements were made in houses in areas with suspected problems. Some of these were near uranium mines. Others were built on backfill made with mine tailings. In one case, houses were built on the site of a factory which made luminous watch dials with radium. Generally, it was assumed that these special circumstances were the source of the radon problem. It was not until the early 1980's that it was realized that most radon problems were due to the radon content of infiltrating soil air in situations in which nothing had been done to increase the radium content of the soil.

A comparison of radon levels in the soil and in houses shows that diffusion of radon through the soil can't account for the rate of radon transfer into a house. This rate can only be accounted for by the bulk flow of radon-laden air through the soil and through leaks in the basement walls and floor.

At first glance it might appear that this flow path is very restricted, and that very little flow is likely from the soil. However, soil air radon concentrations are so high that, on the average, only 0.1% of infiltrating air would have to be drawn from the soil to account for measured indoor radon levels. Soil air will flow into a house through any available opening. This includes cracks in poured concrete floors and walls, cracks between the blocks in concrete block walls, leakage through porous concrete blocks, and cracks around floor or wall penetrations such as plumbing stacks, water lines or sewer clean-out openings. One major crack is the joint between a poured concrete floor and the walls. Intentional openings can also be major sources of radon.

One of the largest sources of radon-laden soil air to be found in houses is a crawl space open to the house and with a bare earth floor. This situation is particularly common in houses which have had rooms added to them. Such a room is often built on a shallow foundation with a crawl space under it, and the crawl space is often open to the rest of the basement. Such houses usually have much higher radon levels than their neighbors.

3.3 Other Sources of Radon

a. Radon in Domestic Water

Domestic water appears to be the second most significant source of radon in houses, more important than building materials. Surface water does not have a significant amount of radon dissolved in it, but ground water can have a very high concentration if it is drawn from a location with a high radium content.

It has been found that public water supplies using ground water are usually quite low in radon. This is probably due in part to the relatively long dwell time of water in public water supplies. Private wells, on the other hand, frequently produce water containing much more radon. Wells in granitic areas have been found to average over 20,000 pCi/L. Using typical water use rates and ventilation rates, this radon concentration in the water will contribute about 2 pCi/L of radon to the indoor air. Of course, this contribution can be exceeded greatly in some houses.

b. Radon from Building Materials

Most mineral building materials contain at least trace amounts of radium, and thus they can emit radon. However, most building materials are much less permeable than the soil, so that unless they are particularly high in radium, they do not emit a significant amount of radon into the living space.

4. RADON MITIGATION

Radon is a serious health problem, but fortunately it is not a hard problem to solve. Experience is showing that basements and floor slabs can be made airtight when they are built, at very little cost. In existing houses, the householder can reduce the radon level by 25% to 50% with a little effort and less than $100 worth of materials.

In houses which have more serious problems, sub-slab suction is proving to be a successful mitigation technique. In this technique, the floor slab and basement walls are sealed as well as possible. Then a duct is installed through the floor slab. A fan is installed to draw air from under the slab and inject it out of doors. (See Fig. 5) This reverses the pressure gradient across the floor, so that the leakage through any cracks and openings which remain in the floor is downwards instead of upward. Subslab suction frequently reduces the radon level by 95%, and sometimes by as much as 99%. This is achieved at a cost which is of the order of $1,000.00 when it is carried out by a contractor. A householder could do it himself for considerably less.

5. CONCLUSION

Radon in houses is a serious health threat, much more serious than any other air quality problem we face. This health threat is well understood, because of the elevated death rates from lung cancer of miners exposed to radon. Fortunately, it is also understood how to build houses which are radon resistant, and how to reduce the levels of radon in existing houses at reasonable cost.

6. BIBLIOGRAPHY

Because this paper is general review of the radon issue, no references have been made to the sources of specific pieces of information. Two sources of further information on the radon issue are listed here. The first provides a good coverage of all aspects of the radon problem. The second is a detailed review of the health risk.

1. Nazaroff, W. W., and Nero, A. V. (Eds.), "Radon and Its Decay Products in Indoor Air", John Wiley and Sons, 1988.

2. Committee on the Biological Effects of Ionizing Radiation, U.S. National Council, "Health Risks of Radon and Other Internally Deposited Alpha-Emitters - BEIR IV", National Academy Press, Washington, D.C., 1988.

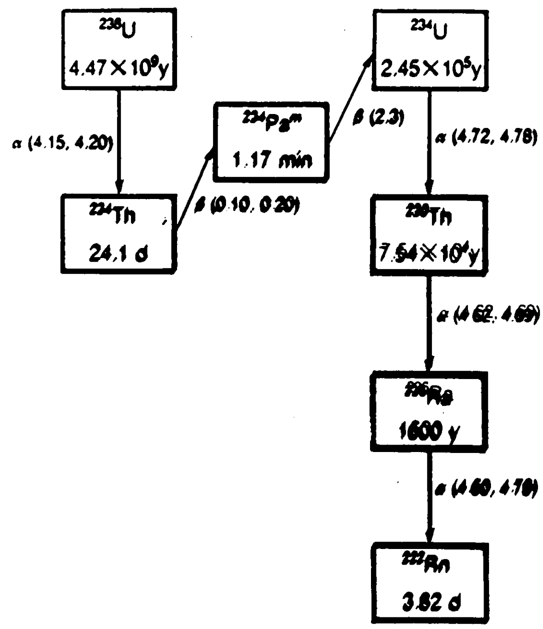


Fig. 1 - Uranium-238 Decay Chain, including Radon-222

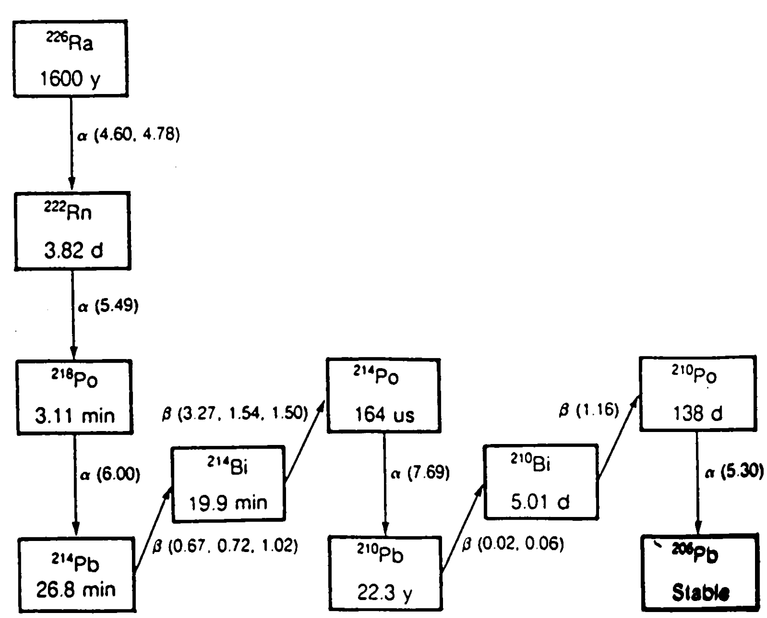


Fig. 2 - The Decay Products of Radon-222

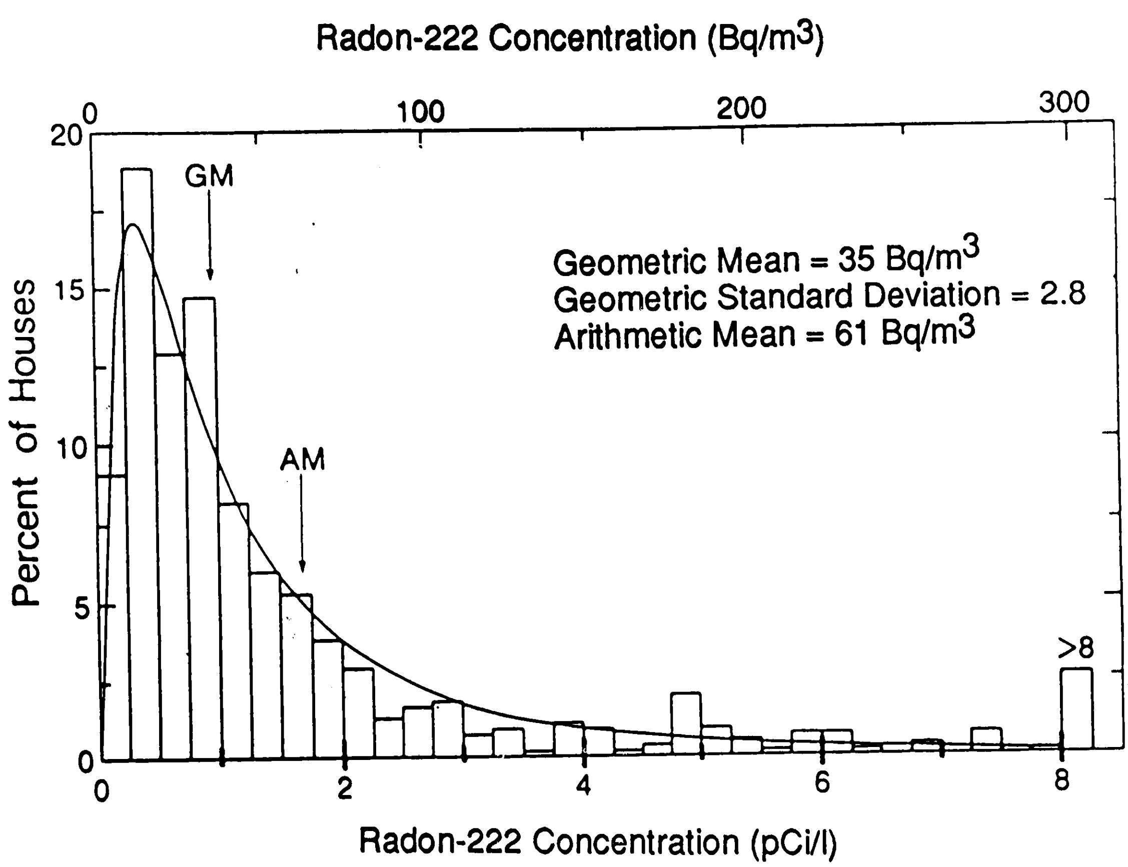
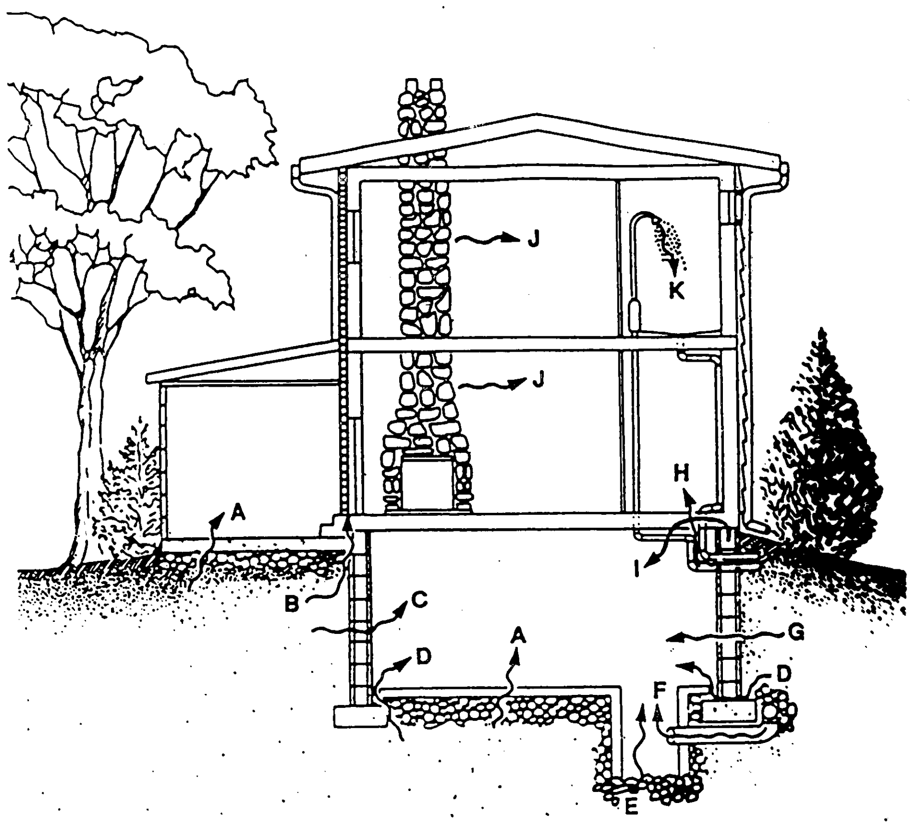


Fig. 3 - Probability Distribution of Radon-222 in U.S. Homes



A. Cracks in concrete slabs
B. Spaces behind brick veneer walls that rest on uncapped hollow-block foundation
C. Pores and cracks in concrete blocks
D. Floor-wall joints
E. Exposed soil, as in a sump
F. Weeping (drain) tile, if drained to open sump
G. Mortar joints
H. Loose fitting pipe penetrations
I. Open tops of block walls
J. Building materials such as some rock
K. Water (from some wells)

Fig. 4 - Major Radon Entry Routes

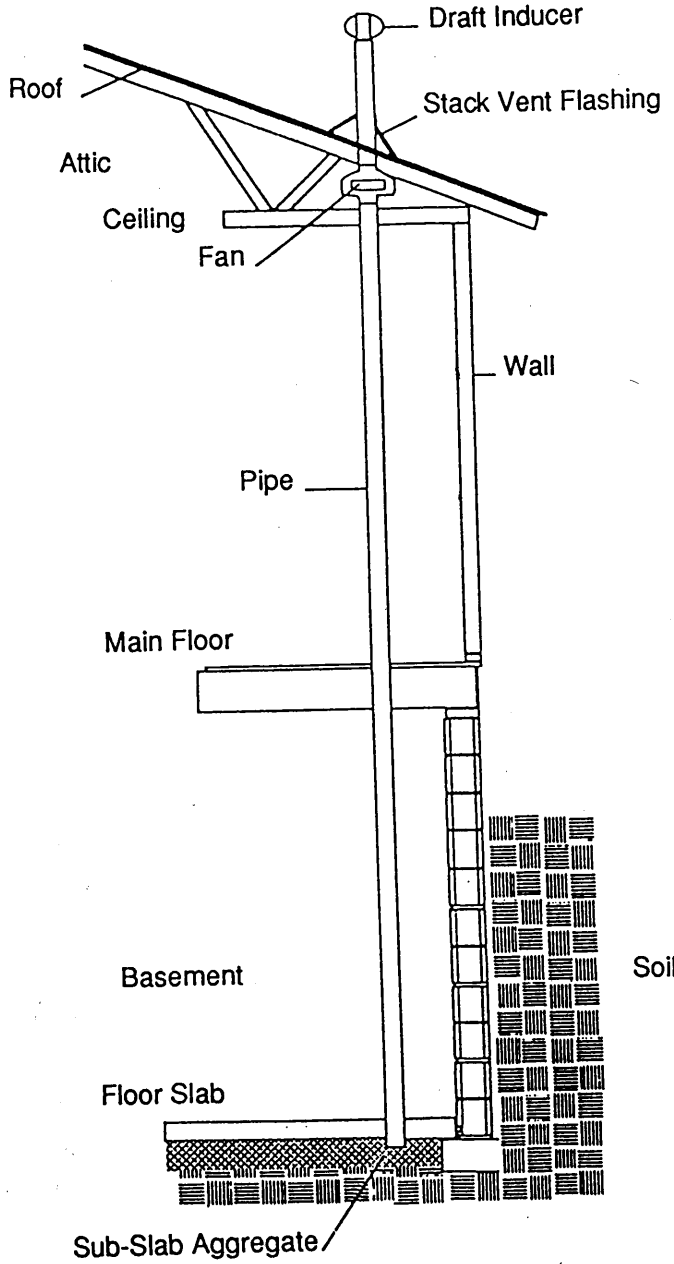


Fig. 5 - Soil Depressurization By Suction on Sub-Slab Aggregate

AUTHOR INDEX

عيسى أبو يوسف اللويشي

https://archive.org/details/@hassan_ibrahem

قطاع الورق والطباعة ـ مطابع الثورة العربية ـ طرابلس

PAPER AND PRINTING SECTOR
ARAB REVOLUTION PRESSES
TRIPOLI

محسن يوسف اللويشي

PAPER AND PRINTING SECTOR
ARAB REVOLUTION PRESSES
TRIPOLI